17:26:23 OCA PAD AMENDMENT - PROJECT HEADER INFORMATION 10/23/95

Active

Project #: E-25-X38 Cost share #: Rev #: 3
Center # : 10/24-6-R7201-0A1 Center shr #: OCA file #:
Work type : RES
Contract#: DE-FG05-91ER54122 Mod #: DELIV SCHEDULE Document : GRANT
Prime #: Contract entity: GTRC

Subprojects ? : N CFDA: 81.049
Main project #: E-25-685 PE #:

Project unit: MECH ENGR Unit code: 02.010.126
Project director(s):
STACEY W M JR MECH ENGR (404)894-3714

Sponsor/division names: US DEPT OF ENERGY / DOE OAK RIDGE - TN
Sponsor/division codes: 141 / 017

Award period: 920701 to 950630 (performance) 950930 (reports)

Sponsor amount	New this change	Total to date
Contract value	0.00	115,715.07
Funded	0.00	115,715.07
Cost sharing amount		0.00

Does subcontracting plan apply ?: N

Title: SUPPORT OF U.S. ITER ACTIVITY

PROJECT ADMINISTRATION DATA

OCA contact: E. Faith Gleason 894-4820

Sponsor technical contact

H. STANLEY STATEN
(301)353-4950

U.S. DEPT. OF ENERGY
OFFICE OF FUSION ENERGY
MAIL STOP 256
WASHINGTON, DC 20585

Sponsor issuing office

MELISSA JOHNSON
(615)576-7599

U.S. DEPT. OF ENERGY
OAK RIDGE OPERATIONS
PROCUREMENT AND CONTRACTS DIVISION
CONTRACT MANAGEMENT BRANCH
BOX 2001, OAK RIDGE, TN 37830-8757

Security class (U,C,S,TS) : U
Defense priority rating : N/A
Equipment title vests with: Sponsor

ONR resident rep. is ACO (Y/N): N
DOE supplemental sheet
GIT X

Administrative comments -
* DELIVERABLE SCHEDULE REVISED TO DELETE FINAL REPORT. IT WILL BE DELIVERED UNDER DR. STACEY'S LATEST PROJECT NUMBER. $\boxed{\text{E-15-626}}$

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CA                         Maintain Closeout                          09-DEC-1997
CA0140                                                               WS12       [AQ]
+-- Document Header ---------------------------------------------------------------+
| Project Number E-25-X38                          Doc Header Id 44802             |
| Project Title SUPPORT OF U.S. ITER ACTIVITY                  Status T            |
| Award Period: From 01-JUL-1992  To 30-JUN-1995                                   |
| PDPI STACEY               WESTON        Sponsor US DEPT OF ENERGY/DOE OAK RI     |
| Contract No DE-FG05-91ER54122                                                    |
| Prime Contract No                                                                |
| Source Document Header 18341          SUPPORT OF US ITER ACTIVITY                |
| OCA File No 02.141.002.93.002                    BOA No 02.141.002.91.005        |
| Security Class U          Unclassified                                           |
|                                                                                  |
+-+-  Closeout ---------------------------------------------------------------+-+
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Title of the project.

Count: *1 <Replace>

E-25-X38

Georgia Tech

Office of Grants and Contracts Accounting

Georgia Institute of Technology
Hinman Building
Atlanta, Georgia 30332-0259
USA
404•894•4624; 2629
Fax: 404•894•5519

March 30, 1993

Ms. Melissa Y. Johnson, Contract Specialist
Special Acquisitions Branch
U. S. Department of Energy
Procurement and Contracts Division
P. O. Box 2001
Oak Ridge, TN 37831-8757

REFERENCE: Grant # DE-FG05-91ER54122

Dear Ms. Johnson,

Enclosed in triplicate is the Financial Status Report (SF-269A) for Grant No. DE-FG05-91ER54122 covering the period June 01, 1992 through February 28, 1993.

If you should have questions or need additional information, please contact Geraldine Reese of this office at (404) 894-2629.

Sincerely,

David V. Welch
Director

DVW/GMR/djt

Enclosures

c: Dr. W. O. Winer, Mech Eng 0405
Dr. W. M. Stacey, Mech Eng 0405
Ms. Danielle Herrmann, OCA/CSD 0420
File: E-25-X38/R7201-0A1

RECEIVED

APR 01 1993

OFFICE OF CONTRACT
ADMINISTRATION

FINANCIAL STATUS REPORT
(Short Form)
(Follow instructions on the back)

1. Federal Agency and Organizational Element to Which Report is Submitted	2. Federal Grant or Other Identifying Number Assigned By Federal Agency	OMB Approval No.	Page	of
U. S. Department of Energy	DE-FG05-91ER54122	0348-0039	1	2 page

3. Recipient Organization (Name and complete address, including ZIP code)

GEORGIA TECH RESEARCH CORPORATION
P. O. BOX 100117
ATLANTA, GEORGIA 30384

4. Employer Identification Number	5. Recipient Account Number or Identifying Number	6. Final Report	7. Basis
58-0603146	E-25-685/R7201-0A0	☐ Yes ☒ No	☒ Cash ☐ Accrual

8. Funding/Grant Period (See instructions) From: (Month, Day, Year)	To: (Month, Day, Year)	9. Period Covered by this Report From: (Month, Day, Year)	To: (Month, Day, Year)
June 01, 1991	June 30, 1995	June 01, 1992	February 28, 1993

10. Transactions:	I Previously Reported	II This Period	III Cumulative
a. Total outlays	126,456.88	65,628.36	192,085.24
b. Recipient share of outlays	-0-	-0-	-0-
c. Federal share of outlays	126,456.88	65,628.36	192,085.24
d. Total unliquidated obligations			2,900.90
e. Recipient share of unliquidated obligations			-0-
f. Federal share of unliquidated obligations			2,900.90
g. Total Federal share *(Sum of lines c and f)*			194,986.14
h. Total Federal funds authorized for this funding period			194,989.00
i. Unobligated balance of Federal funds *(Line h minus line g)*			2.86

11. Indirect Expense

a. Type of Rate *(Place "X" in appropriate box)* ☐ Provisional ☐ Predetermined ☐ Final ☒ Fixed

b. Rate	c. Base	d. Total Amount	e. Federal Share
SEE ATTACHED	MTDC	19,541.15	19,541.15

12. Remarks: *Attach any explanations deemed necessary or information required by Federal sponsoring agency in compliance with governing legislation.*

Questions pertaining to this report should be directed to: Ms. Geraldine Reese (404) 894-2629

GEORGIA TECH'S FISCAL YEAR ENDS JUNE 30

13. Certification: I certify to the best of my knowledge and belief that this report is correct and complete and that all outlays and unliquidated obligations are for the purposes set forth in the award documents.

Typed or Printed Name and Title	Telephone (Area code, number and extension)
David V. Welch, Director, Grants & Contracts Accounting	(404) 894-2629
Signature of Authorized Certifying Official	**Date Report Submitted**
	March 30, 1993

Attachment

U. S. Department of Energy
Grant # DE-FG05-91ER54122
Financial Status Report 03/30/93
Period Covering: 06/01/92 - 02/28/93

	Direct Costs	Indirect Costs	Equipment
FY'91 @ 62.5%	$12,031.56	$ 7,519.73	
FY'92 @ 61.5%	70,443.27	43,322.61	
FY'93 @ 44.9%	41,839.35	16,928.72	4,136.19

REPORT PERIOD

	Direct Costs	Indirect Costs	Equipment
06/01/92 - 06/30/92	$ 4,247.86	$ 2,612.43	
07/01/92 - 02/28/93	41,839.35	16,928.72	4,136.19

Georgia Tech

Office of Grants and Contracts Accounting

E-25-X38

Georgia Institute of Technology
190 Bobby Dodd Way
Atlanta, Georgia 30332-0259
USA
404•894•4624; 2629
Fax: 404•894•5519

February 15, 1994

Ms. Melissa Y. Johnson, Contract Specialist
Special Acquisitions Branch
U. S. Department of Energy
Procurement and Contracts Division
P. O. Box 2001
Oak Ridge, TN 37831-8757

REFERENCE: Grant # DE-FG05-91ER54122

Dear Ms. Johnson,

Enclosed in triplicate is the Financial Status Report (SF-269A) for Grant No. DE-FG05-91ER54122 covering the period March 01, 1993 through December 31, 1993.

If you should have questions or need additional information, please contact Geraldine Reese of this office at (404) 894-2629.

Sincerely,

David V. Welch
Director

DVW/GMR/djt

Enclosures

c: Dr. W. M. Stacey, OIP 0130
Ms. Wanda Simon, OCA/CSD 0420
File: E-25-X38/R7201-0A1
B-10-F52/R7201-0A2 NC Drls

FINANCIAL STATUS REPORT
(Short Form)
(Follow instructions on the back)

1. Federal Agency and Organizational Element to Which Report is Submitted	2. Federal Grant or Other Identifying Number Assigned By Federal Agency	OMB Approval No.	Page	of
U. S. DEPARTMENT OF ENERGY	DE-FG05-91ER54122	0348-0039	1	2 pages

3. Recipient Organization (Name and complete address, including ZIP code)
GEORGIA TECH RESEARCH CORPORATION
P. O. BOX 100117
ATLANTA, GA 30384

4. Employer Identification Number	5. Recipient Account Number or Identifying Number	6. Final Report	7. Basis
58-0603146	E-25-685/R7201-0A0	☐ Yes ☒ No	☒ Cash ☐ Accrual

8. Funding/Grant Period *(See Instructions)* From: (Month, Day, Year)	To: (Month, Day, Year)	9. Period Covered by this Report From: (Month, Day, Year)	To: (Month, Day, Year)
June 01, 1991	June 30, 1995	March 01, 1993	December 31, 1993

10. Transactions:	I Previously Reported	II This Period	III Cumulative
a. Total outlays	192,085.24	130,110.76	322,196.00
b. Recipient share of outlays	-0-	-0-	-0-
c. Federal share of outlays	192,085.24	130,110.76	322,196.00
d. Total unliquidated obligations			-0-
e. Recipient share of unliquidated obligations			-0-
f. Federal share of unliquidated obligations			-0-
g. Total Federal share *(Sum of lines c and f)*			322,196.00
h. Total Federal funds authorized for this funding period			322,196.00
i. Unobligated balance of Federal funds *(Line h minus line g)*			-0-

11. Indirect Expense

a. Type of Rate *(Place "X" in appropriate box)* ☒ Provisional ☐ Predetermined ☐ Final ☐ Fixed

b. Rate	c. Base	d. Total Amount	e. Federal Share
SEE ATTACHED	MTDC	37,412.12	37,412.12

12. *Remarks: Attach any explanations deemed necessary or information required by Federal sponsoring agency in compliance with governing legislation.*

Questions pertaining to this report should be directed to: Ms. Geraldine Reese (404) 894-2629

GEORGIA TECH'S FISCAL YEAR ENDS JUNE 30

13. Certification: **I certify to the best of my knowledge and belief that this report is correct and complete and that all outlays and unliquidated obligations are for the purposes set forth in the award documents.**

Typed or Printed Name and Title	Telephone (Area code, number and extension)
David V. Welch, Director, Grants and Contracts Accounting	(404) 894-2629

Signature of Authorized Certifying Official	Date Report Submitted
	February 15, 1994

Attachment

U. S. Department of Energy
Grant # DE-FG05-91ER54122
Financial Status Report (02/15/94)
Period Covering: 03/01/93 - 12/31/93

	Direct Costs	Indirect Costs	Equipment
FY'91 @ 62.5%	$12,031.56	$ 7,519.73	$
FY'92 @ 61.5%	70,443.27	43,322.61	
FY'93 @ 44.9%	81,252.37	34,625.16	4,136.19
FY'94 @ 37.0%	53,285.62	19,715.68	

REPORT PERIOD

	Direct Costs	Indirect Costs	Equipment
03/01/93 - 06/30/93	$39,413.02	$17,696.44	
07/01/93 - 12/31/93	53,285.62	19,715.68	

E 25 · 12
#1

Proposal To the
U. S. DEPARTMENT OF ENERGY
For Renewal of Research on

"SUPPORT OF U.S. ITER ACTIVITY"
DOE GRANT DE-FG05-91ER54122

by

Fusion Research Center
Georgia Institute of Technology
Atlanta, Georgia 30332

August 27, 1992

Principal Investigator:	Dr. W. M. Stacey
Title:	Callaway Professor
Department Affiliation:	Nuclear Engineering Program School of Mechanical Engineering
Telephone:	(404) 894-3714
Proposed Start Date:	January 1, 1993
Proposed Duration:	1 Year
Funding Requirements:	$127,207

Endorsements:

W. M. Stacey, Jr.
Principal Investigator

Date: 8-25-92

W. M. Stacey, Jr., Director
Fusion Research Center

Date: 8-25-92

SUPPORT OF U.S. ITER ACTIVITY

ABSTRACT

It is proposed to continue our work in support of the U.S. participation in the ITER Engineering Design Activity (EDA) as part of the U.S. Home Team Design Activity, including associate JCT member support. Our contributions will be in two task areas. In the System Studies activity we will continue our participation in the development and use of the SUPERCODE, the fast 1½-D systems and operational code for the ITER EDA. In the Confinement and Plasma Performance task area, we will continue our work in the modeling and analysis of radiative edge operating scenarios for ITER with impurity seeding. In addition, we will continue our work on burn control and the development of burn control requirements for ITER.

1. SYSTEM STUDIES TASK AREA

1.1 SUPERCODE Development

Progress Report of Work To Date:

We have been participating in the development of the SUPERCODE, the new fast 1½-D systems and operational code for the ITER EDA [1], since its inception in 1990. We have provided models and routines for the self-consistent, profile-dependent evaluation of neutral beam deposition, heating and current drive [2], the implementation of theory-based transport models including the Rebut Critical Electron Temperature Gradient model, the calculation of the bootstrap current, and the accurate calculation of the peak neutron wall load (modules *Beams, Boots, NDWallLoad*, and routines *rebutChiElec, rebutChiIon, neoclassicalChi*, and *nocentiniChi* of the *VarTr* module). These routines greatly enhance the capabilities of the SUPERCODE and extend its usefulness as a modern systems analysis tool for the design of ITER and other future tokamak reactors.

At the same time, we have provided benchmarks with the transport code WHIST, and have used the SUPERCODE for the study of possible operating scenarios for ITER.

Proposed Work:

The SUPERCODE is already operational and is being used for the analysis of ITER EDA operating scenarios. During the course of the EDA, it is expected that the code will be extensively used by the members of the Joint Central Team. At the same time, the code will be continuously maintained and upgraded. We intend to continue our contributions to the development of the SUPERCODE during the fiscal year 1993. For this, one of us (JM) could become an associate member of the JCT for a closer cooperation between developers and users of the code. Specifically, regarding the upgrading of the physics models of the code, we will provide modules for:

- ICRF heating and current drive: Most accurate calculations for fast wave heating and current drive are performed using time-consuming numerical codes based on ray tracing or full wave techniques. Such methods cannot be implemented in the SUPERCODE, whose primary requirement is computational speed. Instead, a routine based on M. Brambilla's recent work [5] will be developed, that is based on analytic estimates of the wave behavior near resonances, and on simplifications of the real geometry. The routine will be benchmarked extensively against full wave calculations performed by D. Batchelor's group at ORNL.

- <u>ODE solvers for time-dependent capabilities:</u> The current version of the SUPERCODE can run only in steady-state mode. While this is sufficient for the majority of system and optimization runs, some important phenomena such as burn control scenarios and start-up simulations cannot be analyzed. We intend to provide the required numerical routines that will give time-dependent capabilities to the code.
- <u>Calculation of fueling sources:</u> In the current version of the SUPERCODE, only the temperature profiles are transported. The density profiles remain fixed, and only the average density and the edge-to-average density ratio can change. Although the code has the capability to transport the densities of the different species built-in, to activate it requires routines for the calculation of the relevant fueling sources. We will develop and implement such routines based on fast but accurate models, for both pellets and gas puffing fueling.
- <u>Impurity radiation routines:</u> Currently, impurity radiation is included in the SUPERCODE using the simple fits that were developed during the ITER CDA [6]. However, a more accurate impurity model will be needed in order to investigate operating scenarios relying on impurity seeding or gas injection. We are already studying such radiative edge operating scenarios (see the Impurity Seeding task below) using a time-dependent 1½-D transport code, coupled with multi charge state impurity transport routines. While direct implementation of such routines into the SUPERCODE would not be practical, we do expect to use the experience gained from our impurity transport simulations to come up with simpler models that would contain most of the essential physics. Such models could be based on the transport of a few important charge states, or on parametric fits that would be derived from the more accurate full impurity transport simulations, and would be valid in the parameter range of interest.

In addition we will provide benchmarks with the transport code WHIST, and will assist the LLNL SUPERCODE group with other, non-physics, computational aspects of the project as needed.

2. POWER & PARTICLE CONTROL

2.1 Modeling of Radiative Edge / Impurity Seeding

<u>Progress Report of Work To Date:</u>

During the last two years, we have been involved in the evaluation of ITER operating scenarios with impurity seeding [7-9]. Such scenarios have been proposed as a way to alleviate the divertor heat load through increased radiation levels from the plasma edge and divertor regions. Recent experimental results [10] have also demonstrated that plasma conditions in which a large part of the power is exhausted by radiation can be obtained and maintained without serious contamination of the core plasma.

For the purposes of this work, a multi charge state impurity transport routine has been developed and implemented in the WHIST 1½-D transport code, providing us with an advanced computational capability. Unlike previous studies that analyzed the effect of impurity seeding by assuming a background plasma with constant properties, our treatment allows for a more self-consistent analysis of the effect of enhanced edge radiation on the power balance of the core and edge plasmas.

Our results have indicated that impurity seeding is a promising method to alleviate the deleterious divertor conditions, specially for the hybrid and steady-state modes of operation of ITER.

<u>Proposed Work:</u>

We propose to continue our modeling and analysis of radiative edge operating scenarios for ITER with impurity seeding, building upon our substantial computational capability in this area. Our first task during the new year would be to implement a simple but comprehensive divertor model for a better estimation of the peak divertor heat load. The model will be based on the well-known two-point divertor models [11-12], but with extensions for an accurate estimate of the radiative power levels from impurities in the SOL and divertor chamber and with inclusion of effects due to neutrals. This divertor model would be coupled, as a boundary condition, to our 1½-D transport calculational model. A Ph.D. student of our group is doing his thesis on this subject. The second task that we will undertake is an analysis of the effectiveness of impurity seeding in the plasma edge in reducing the divertor heat load in ITER, in both the driven and ignited modes of operation, thereby exploiting our (possibly unique) computational capability. We will also examine the sensitivity of our calculations to the transport models for the impurities and the main plasma species. In addition, the important issue of edge thermal stability during impurity seeding will be investigated in detail.

3. CONFINEMENT AND PLASMA PERFORMANCE TASK AREA

3.1 Burn Control Analysis

<u>Progress Report of Work To Date:</u>

During the current year we have been doing mostly maintenance work, upgrading our computational tools for the burn control activity. In particular, we have been upgrading the MHD equilibrium routines of the WHIST 1½-D transport code (the older routines had problems finding MHD equilibria for a large number of possible operating points of the CDA and HARD ITER designs) and installed new theory-based transport models.

Proposed Work:

For the new year we are planning to carry out simulations of burn control scenarios for the ITER EDA design, using WHIST and the recently developed fast 1½-D systems and operational code for the ITER EDA, the SUPERCODE. The use of a systems code will make it possible to include in our analysis in a self-consistent way the effect of thermal instabilities on the different parts of the reactor, as well as to assess the constraints and evaluate the requirements that these parts may impose on the controller. The advanced physics models of the SUPERCODE will ensure that no compromises are made in the evaluation of the physics-related parts of the calculations. Emphasis will be placed on a number of critical issues, including the definition of the minimum diagnostic requirements for controllability, the identification of worst case transients, and the study of the effect of perturbations introduced by sawteeth oscillations and pellet injection on the thermal stability of ITER designs. Possible new methods of burn control, based on control of the edge conditions and hence of the confinement properties, will be studied.

REFERENCES

1. S. W. Haney, W.L Barr, J. A. Crotinger, L. J. Perkins, C. J. Solomon, E. A. Chaniotakis, J. P. Freidberg, J. Wei, J. Galambos, J. Mandrekas, "A SuperCode for Systems Analysis of Tokamak Experiments and Reactors," *Fusion Technology*, **21**, 1749 (1992).
2. J. Mandrekas, *Physics Models and User's Guide for the Neutral Beam Module of the SuperCode,* Georgia Tech Fusion Report GTFR-102, August 1992, Atlanta, GA.
3. J. Mandrekas, S.W. Haney, L. J. Perkins, and J. Galambos, "Current Profile Control Simulations with the SuperCode," *to be presented at the 34th Annual APS DPP meeting*, November 16-20, 1992, Seattle, WA.
4. L.J. Perkins, S.W. Haney, W.M. Nevins, J.D. Galambos, J. Mandrekas, and R.L. Miller, "SSAT Systems and Operational Studies with SuperCode," *to be presented at the 34th Annual APS DPP meeting*, November 16-20, 1992, Seattle, WA.
5. M. Brambilla, "An Improved Routine for the Fast Estimate of Ion Cyclotron Heating Efficiency in Tokamak Plasmas, " IPP 5/44, February 1992.
6. N.A. Uckan, and ITER Physics Group, *ITER Physics Design Guidelines*: 1989, IAEA, Vienna, 1990.
7. J. Mandrekas, H. He, W.M. Stacey, and L.J. Perkins, "Impurity-Seeded Operating Scenarios for ITER, " *Bull. Am. Phys. Soc.*, **35**, 1923 (1990).
8. J. Mandrekas, H. He, W.M. Stacey, "Impurity Seeding Simulations for ITER," *Bull. Am. Phys. Soc.*, **36**, 2276 (1991).
9. H. He, J. Mandrekas, W.M. Stacey, "Radiative Edge Simulations for ITER," *to be presented at the 34th Annual APS DPP meeting*, November 16-20, 1992, Seattle, WA.
10. T.W. Petrie, et al., "Radiative Divertor Experiments in DIII-D," *Bull. Am. Phys. Soc.*, **35**, 2024 (1990).
11. W.D. Langer, C.E. Singer, *IEEE Trans. Plasma Sci.*, **3**, 163 (1985).
12. W.L. Barr, "A model for the Edge Plasma Near a Poloidal Divertor," *Fusion Technology*, **19**, 498 (1991).

E-25-X38
2

Proposal To The
U. S. DEPARTMENT OF ENERGY
For Continuation of Research on

"SUPPORT OF U.S. ITER ACTIVITY"
DOE GRANT NO. DE-FG05-91ER54122
by
Fusion Research Center
Georgia Institute of Technology
Atlanta, Georgia 30332

August 13, 1993

Principal Investigator:	**Dr. W. M. Stacey**
Title:	**Callaway Professor**
Department Affiliation:	**Nuclear Engineering Program** **School of Mechanical Engineering**
Telephone:	**(404) 894-3714**
Proposed Continuation Date:	**January 1, 1994**
Proposed Duration:	**1 Year**
Funding Requirements:	**$293,855**

Endorsements:

W. M. Stacey, Jr.
Principal Investigator

Date: 8-13-93

W. M. Stacey, Jr., Director
Fusion Research Center

Date: 8-13-93

SUMMARY

We propose to expand our involvement in the US Edge Physics effort in support of the ITER Project. We have identified four specific tasks in the areas of **ITER DIVERTOR ANALYSIS** which are important to ITER and in which we have a special capability. These areas are: 1) implementation of a DEGAS-compatible collision-escape probability neutral particle transport model; 2) characterization studies of viscous forces and implementation of a full viscosity formalism in UEDGE; 3) coupled plasma core-plasma edge-SOL-divertor analysis of radiative electron cooling; and 4) comparative analysis of atomic and molecular effects in the presheath region.

We propose to continue our activities in support of 5) **SUPERCODE DEVELOPMENT & ANALYSIS**. This includes continued module development and application of the code in support of design analyses.

We propose to expand our activity in 6) **BURN CONTROL**. This will utilize our highly developed capabilities in this area to identify burn control mechanisms and scenarios for ITER.

I. NEUTRAL PARTICLE TRANSPORT

A new computational model for neutral particle transport in the divertor and scrape-off layer is under development. This model is based on precomputed transmission and escape probabilities, which should lead to a model with reasonable accuracy and computational economy. Funding for development and testing of the model has been proposed separately to DOE/OFE. ITER is supporting the adaptation of the model to the geometric representation used in DEGAS, so that it can be incorporated as a computational economical neutral transport option in DEGAS, and it is proposed that this support be continued.

A. BACKGROUND

Neutral particle transport can be calculated to within the accuracy imposed by uncertainties in the data for atomic and molecular processes by Monte Carlo, provided that a sufficient number of particle histories are followed to obtain "good" statistics. However, the computational time required for such calculations precludes their use on a routine basis.

There are certain limitations to the deterministic neutral transport methods that have been used for plasma edge calculations, as discussed in Ref. [1]. Diffusion theory, perhaps the most used method, is of limited accuracy in many edge plasma situations where the assumption of linear anisotropy in the angular distribution can not be justified (e.g. near a material wall or an interface across which the neutral flow is highly unidirectional). Extensions to higher order spherical harmonics is straightforward in 1D, but becomes complex in 2D. The discrete ordinates method, which has been highly developed in 2D for neutron transport, has only been formulated in regular (e.g. rectangular, cylindrical) geometries, which are not suitable for the representation of plasma edge regions. Integral transport models are economical when ionization or other "removal" processes dominate charge-exchange or other "scattering" processes, but become quite complex and time-consuming when multiple "scattering" events must be followed.

The computational method that we are developing may be considered as a variant of integral transport theory. Uncollided transmission of neutral particles across a region from one bounding surface to another is calculated by integral transport theory and can be precomputed as transmission probabilities which depend only on the mean-free-path of the region. The transmission of neutral particles across a region from one bounding surface to another via a series of charge-exchange or other "scattering" events, which is the computational intense aspect of an integral transport model, is replaced by the calculation of escape probabilities based on chord distribution theory, which leads to simple limiting expressions that can be used to formulate a simple rational approximation.

B. PROPOSED WORK

We have proposed to DOE/OFE to undertake the development and testing of the transmission-escape probabilities method for neutral particle transport, and are undertaking this development on a limited scale, pending receipt of support therefor.

We propose to ITER to continue our work to adapt the transmission-escape probabilities model to the DEGAS geometry package. The objective is a DEGAS - compatible module which can be used as a computationally economical neutral option by codes with can interface with DEGAS. We further propose to develop a code for processing the atomic, molecular and surface data used by DEGAS into the form needed in the transmission-escape probabilities model.

C. EFFORT, TIME & BUDGET

We anticipate that the development of a DEGAS-compatible computational module and the associated data processing code will be carried out over a period of about two years, in parallel with the development and testing of the method. Initial versions would be available for testing during the first year.

The proposed effort is intended to require 5% of the Dr. Stacey's time, 5% of Dr. Mandrekas's time, and 50% of a Post-Doc. Support of this effort will require about $50K per year, allowing for fringe, overhead and travel.

D. REFERENCE

1. W. M. Stacey, "A Transmission/Escape Probabilities Model for Neutral Particle Transport in the Outer Regions of a Diverted Tokamak", Georgia Tech Fusion Report GTFR-105 (1993); also Proc. Sherwood Fusion Theory Conf. (1993).

II. VISCOSITY

It has been established from order-of-magnitude ordering arguments that viscosity produces order unity effects on the calculated flow fields in tokamak scrape-off layers and divertor channels and on the predicted peaking of the energy transported to the divertor collector plate; yet a full treatment of viscosity is not commonly included in calculations of these quantities. It is proposed to: 1) quantitatively characterize the effect of viscous forces that would be predicted throughout the scrape-off layer and divertor channel of existing tokamaks and of ITER, based on a recently developed formalism; and 2) incorporate the recently-developed viscosity formalism in the 2D code UEDGE.

A. BACKGROUND

The calculation of the flow of plasma ions in the scrape-off layer and divertor of tokamaks is a subject that is receiving increased attention because of its importance to the prediction of energy transported to the divertor collector plates and because of the apparent relationship between shear in the flow field and the L-H transition in energy confinement regime. Most calculations of the flows are based on fluid models and treat the viscosity approximately with a parallel term and an anomalous radial term (e.g. Refs.1-6). Such a reduced treatment of viscosity is perhaps justified in the plasma core, where the relatively long radial gradient scale lengths of the pressure and velocity distributions generally result in the viscosity being smaller than other terms in the equations. However, in the scrape-off layer(and in the plasma edge just inside the separatrix, as well) there is ample theoretical [7] and experimental [8-11] evidence that the radial gradient scale lengths of the pressure and velocity are small, of order of the gyroradius. With such a small radial gradient scale length, the viscous force and energy flux terms become comparable with the pressure and other leading order terms in the fluid equations, and omission of important viscous flow cross-derivative terms can introduce significant error.

The effects of viscous forces and energy fluxes on the nature of the fluid equations and on the prediction of radial peaking in the energy flux incident on the divertor collector plate, in the small-radial-gradient-scale-length (SRGSL) ordering, has been investigated theoretically [12]. It was found that the SRGSL ordering raises viscous terms to leading order and fundamentally alters the character of the fluid equations. A viscous drift term of the same order as the diamagnetic and ExB drifts obtains. Important viscous forces result from cross-derivatives of the flow field and can not be modeled by a purely parallel plus anomalous radial representation of viscosity. Order-of-magnitude estimates indicate that viscous-driven radial energy fluxes in the scrape-off layer and divertor channel have an order unity effect in reducing the radial peaking of energy fluxes that are transported along field lines to divertor collector plates. Although no studies have been made, yet it seems intuitive that viscous forces of this magnitude would also greatly affect the Ohm's law governing plasma currents in the scrape-off layer and divertor. All of this has profound implications for both the interpretation of present experiments using fluid code calculations , which treat viscosity approximately, and for the prediction of power peaking on the divertor collector plate in ITER (and TPX) using such codes.

The previous study [12] establishes, from order-of-magnitude estimates, that viscous forces and energy fluxes can be important within the scrape-off layer and divertor channel of tokamaks. It should be possible to use the same formalism in conjunction with existing 2D fluid calculations of energy and particle flows to quantitatively characterize where viscous terms are important within the scrape-off layer and divertor channel and to establish specific criteria for the inclusion or omission of viscous terms. Such a characterization would quantitatively establish the importance of omitted viscous effects in calculations of particle and energy flows in the divertor and scrape-off layer of present experiments and future devices. Since the viscous terms would significantly complicate the calculation and may not be needed everywhere in the scrape-off layer and divertor, such a characterization and associated criteria would also be useful in guiding the modification of existing codes to include the most important viscous effects. Such a study would also provide a quantitative estimate of how the results of present calculations of flows would be changed by the inclusion of viscous terms and of how these viscous changes would alter phenomena such as the peaking in the energy flux incident on the divertor collector plate. Given the urgency of resolving the divertor energy loading issue for ongoing designs of ITER (and TPX), we propose to use the formalism of Ref [12] to perform a calculational study to characterize viscous forces and their effects in the scrape-off layer and divertor channel of existing and planned tokamaks, with the objectives of understanding the magnitude and character of the changes that would result in existing fluid calculations if viscous effects were incorporated and of establishing criteria for inclusion of viscous effects. We will also characterize the effect of viscous forces on the plasma currents in the scrape-off layer and divertor, using a formalism which we now are developing separately. One prime intention of such a study is to provide a timely, quantitative estimate of the reduction in the predicted peak energy flux to the divertor collector plate that would result from the inclusion of viscous effects in 2D fluid codes.

We further propose to implement the viscous formalism in an existing 2D fluid code. We will then repeat the above characterization studies, with the intent of providing a quantitative understanding of the influence of viscous effects on particle and energy flows and on currents in the scrape-off layer and divertor channel and on reduction in the radial peaking of the power flow to the divertor plates.

The previous study [12] was carried out within the framework of fluid theory. Questions have been raised [13] about the validity of the conventional derivation of fluid theory from kinetic theory for ions in the scrape-off layer and divertor channel. We further note the need to rederive the fluid viscosity formalism from kinetic theory for a multi-ion-species plasma that is interacting with neutral species. It is likely that such a new theory will affect the calculated values of viscosity coefficients, possible that it will alter the mathematical structure of the viscous forces, but unlikely that it will change the predicted order of magnitude of the viscous effects. Thus, we believe that the proposed study will provide significant insights which may be altered in detail but not in magnitude by future developments in the theory. (We are separately developing, from kinetic theory, a fluid representation of viscosity in a multi-species plasma in the presence of an interacting neutral species, with the objective of providing a viscosity formalism and a general fluid formalism that are appropriate for modeling plasma ions, impurities and electrons in the scrape-off layer and divertor channel of tokamaks).

B. PROPOSED WORK

Two separate, but related, activities are proposed: 1) quantitative characterization of viscous forces that would be predicted throughout the scrape-off layer and divertor channel of existing and future tokamaks; and 2) implementation of the viscous formalism in an existing 2D fluid code.

B.1 Quantitative Characterization of Viscous Forces

Two-dimensional calculations of flow velocities throughout the scrape-off layer and divertor channel of existing tokamaks and ITER designs will be used to evaluate the magnitude of the viscous drift, viscous forces and viscous energy fluxes defined in Ref. [12]. Estimates of how the calculated flow velocities and currents would change, of how much the predicted peaking of the energy flux on the collector plate will change, and of other quantities of interest will then be made. The 2D flow velocities will be calculated with existing codes, and the results of other groups will be used when readily available. We plan to use the 2D code UEDGE, which is available at NERSC, for this purpose. Calculations for existing experiments (e.g. DIII-D, ALCATOR C-Mod) and ITER will be made, as necessary to characterize the various aspects of the problem.

Guided by the above calculations, model calculations will be performed to quantitatively characterize the importance of the viscous terms defined in Ref. [12] and to develop criteria for their inclusion in fluid computations. Simplified geometries that are representative of various aspects of the flow problem in tokamak scrape-off layers and divertor channels will be modeled.

At a later time, when the viscous representation is incorporated into UEDGE, we will utilize this code to confirm and extend the above results. Changes in flow velocities, currents and the peaking of the energy flux on the divertor collector plate due to viscous effects will be calculated directly. The criteria for inclusion of viscous effects will be checked in realistic geometries and modified as required.

B.2 Implementation of Viscous Formalism in UEDGE

The existing 2D fluid codes that have been developed to study the scrape-off layer and divertor channel of tokamaks (e.g. [1-6]) are based on a variety of coordinate systems and representations of the fluid equations. The viscous representation depends on the choice of representation of the fluid equations and upon the coordinate system that is adopted; thus the proper viscous representation for each code probably differs from either of the representations given in Ref. [12]. We propose to develop a representation appropriate for UEDGE and to implement this in that code.

C. EFFORT, TIME AND BUDGET

Because of the PI's rather extensive previous work (see Refs. 12 and 14) in the area of viscosity, the proposed work can be carried out rather expeditiously, without the necessity of a lengthy review and startup process. It is intended that the characterization study B.1 be carried out by a Post-Doc working under the direct supervision of the PI. Initial results should be available within 3-6 months of initiation of the project, and it should be possible to conclude and document a comprehensive study within another 18 months. The work on implementing the viscous formalism in UEDGE will be ongoing over the two years of the proposed project.

The proposed effort is intended to require 5% of the Dr. Stacey's time, 5% of Dr. Mandrekas's time, and 50% of a Post-Doc. Support of this effort will require about $50K per year, allowing for fringe, overhead and travel.

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III. RADIATIVE ELECTRON COOLING

We propose to use a coupled core/SOL-divertor transport code package that we have partially assembled to investigate the possibility of radiatively cooling the electrons, on both sides of the separatrix, so as to reduce the electron component of the power flow to the divertor collector plate. The analysis will include an evaluation of the efficacy of methods for preventing impurities in the edge plasma from penetrating to the core plasma.

A. BACKGROUND

Reduction of the power flow to the divertor collector plate, in particular the highly peaked electron component, is a major feasibility issue for ITER (and for TPX and other future tokamaks). While there appear to be possible solutions for reducing the ion power flux to the divertor [1], feasible means for reducing the electron power flux remain to be identified. Since the electrons apparently transport energy rapidly to the divertor collector plate along a rather narrow channel just outside the separatrix and do not collisionally equilibrate with the ions, it is necessary to find a mechanism which cools the electrons directly.

Radiative cooling of the electrons by impurities is a possible mechanism for reducing the electron component of the power flux to the divertor plate. However, it is not clear that radiative cooling can overcome the large parallel electron transport in the scrape-off layer and divertor. The effective radiative region in the divertor channel will be confined to a rather narrow electron temperature range, hence spatial region, unless impurity ions in low ionization states can be transported rapidly from the vicinity of the collector plate upstream into the radiative region, which is somewhat at odds with the objective of entraining impurities within the divertor channel. This suggests that radiative cooling of electrons before they cross the separatrix, while they are confined in the plasma edge region, might be a possible solution to the divertor energy flux problem. However, such a solution is only useful if the impurities can be confined to the plasma edge region and prevented from diffusing into the plasma core region. There is recent experimental evidence [2] from DIII-D that the electrons can be radiatively cooled in the plasma edge/SOL by MARFEs, and this has motivated plans to experimentally study radiatively cooling electrons by impurity injection inside the separatrix--just the concept proposed here. There is evidence [3] that impurities can be inhibited from diffusing into the plasma core by a positive radial electric field in the edge plasma.

B. PROPOSED WORK

We propose to analyze the possibility of radiatively cooling plasma electrons, both before and after they cross the separatrix. The emphasis will be on cooling with impurities that are trapped in the plasma edge region inside the separatrix, but we will also take into account cooling by impurity radiation in the scrape-off layer and divertor channel.

We will use the 1-1/2D plasma transport code WHIST [4], which has been operational at Georgia Tech during the last few years and has been used extensively for our ITER burn control studies [5]. We have recently modified WHIST to include multi-charge-state impurity transport, an improved MHD equilibrium model (Hirshman's VMEC code), and a simple but comprehensive scrape-off layer and divertor model. This advanced computational capability allows for a more self-consistent treatment of the effect of enhanced edge radiation on the power balance of the coupled core plasma-edge plasma-scrape off layer-divertor; it has been used already in the evaluation of impurity seeding scenarios for ITER [6]. We are currently extending our single-fluid 2-point model of the scrape-off layer and divertor to treat electron and ion energy transport separately, in order to be able to model explicitly the different energy transport processes along the magnetic field lines for the ion and electron channels. We are in the process of incorporating impurity radiation in the scrape-off layer and divertor, using a simple radiation model similar to that of McCracken and Pedgley [7] upgraded using a residence time correction to take into account non-coronal equilibrium effects. We also plan to incorporate an improved neutrals model to treat atomic and molecular effects more accurately. At a later stage, we plan to couple our multi-charge-state WHIST core transport code with a multi-charge-state 1D fluid code for the scrape-off layer and divertor (e.g. NEWT-1D [8]).

The analysis will initially consist of "injecting" impurities into the edge plasma inside of the separatrix, calculating their transport and radiative electron cooling with WHIST to obtain electron, ion and impurity particle fluxes and electron and ion energy fluxes into the SOL at the midplane, then using the 2-point SOL/divertor model to calculate the electron and ion power fluxes to the divertor collector plate. We will also calculate the impurity diffusion to and radiative cooling of the plasma core, with and without inhibiting mechanisms such as radial electric field modification by NBI-driven rotation in the edge plasma region. We will attempt to model the impurity "injection" from the SOL consistently, but this aspect can be made fully consistent only when we replace the 2-point SOL/divertor model with a 1D fluid code with impurity transport at a later stage.

We will study various impurity species, including intrinsic low-Z impurities (Be) and externally supplied intermediate-Z impurities. We will also identify and study a variety of methods for modifying edge impurity transport by modification of the radial electric field and otherwise. Current models of the ITER plasma and edge conditions will be used in the studies. The overall objective of the analyses will be to assess if impurities can be used to radiatively cool electrons in the plasma edge before they cross the separatrix in order to reduce the electron component of the power flux on the divertor collector plate, without deleterious effect on the plasma core.

We also plan to analyze the impurity seeding experiments in DIII-D, which will provide confirmation of the computational model used for the ITER analyses. This effort will take place prior to or concurrent with the ITER analyses, depending on the timing of the experiments. Preliminary discussions with Stambaugh to this end have been held.

C. EFFORT, TIME AND BUDGET

This work will be carried out over about 2 years as Ph.D. thesis research by Mr. Heping He, who has already spent about that amount of time becoming familiar with the area and modifying the WHIST code. Supervision of the work will be done by Drs. Stacey and Mandrekas, involving about 5% of their time. Support of this effort will require about $35,000 per year for 2 years, allowing for fringe, overhead and travel.

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IV. ATOMIC AND MOLECULAR MECHANISMS & DATA IN THE SCRAPE-OFF LAYER AND DIVERTOR

We propose to perform a comparative analysis of cross sections for atomic and molecular collision processes that could be important for analysis of radiative cooling in the scrape-off layer and divertor regions. In part, we shall use existing critically evaluated data bases using the ALADDIN data transfer format recommended by the IAEA. We anticipate that the compendia will inadequately cover processes involving secondary species created by ionization and excitation. An analysis of the sensitivity of the model prediction to the input data base will identify such inadequacies which in turn should be a major focus for further coordinating activities of the IAEA in support of ITER. Where appropriate, we shall supplement the existing data bases with cross section estimates based on established scaling relations.

A. BACKGROUND

Neutral and fluid transport codes require, as an input, cross section information for the various collisional processes. As far as possible, one should utilize critically assessed data bases which are approved by experts in the atomic collision field and readily available to all modeling groups. The IAEA Atomic and Molecular Data Unit has been responsible for coordinating the provision of data bases for Fusion; Dr. Thomas has contributed to a number of these compendia through the IAEA and through the ORNL data center. Surprisingly, these extensive, assessed data tabulations have only rarely been incorporated into modeling codes. We plan to use a relatively simple, 1D, multigroup neutral transport code to test the completeness of the available data bases and the utility of the ALADDIN data transfer format adopted by the IAEA. Moreover the code will permit us to perform a sensitivity analysis to determine which processes dominate the behavior of the plasma in the edge and divertor; this will lead to identification of processes where collisional information is inadequate and where further work should be coordinated by the IAEA.

Energy degradation of electrons in the SOL occur first by inelastic, ionization and excitation events which exhibit peak cross sections in the region of 100's eV, followed by elastic events as energy declines; these may be termed the primary events. But a satisfactory analysis must include the further transport of the secondary products of the initial events which will include ions, metastables and photons; recombination, molecular rearrangement and Penning ionization are likely to be the processes dominating transport of these secondary products.

The data bases provide an adequate coverage of the primary interactions of charged particles with fuel and common impurities. They are, however, rather weak in the coverage of transport of the secondary products. In the modeling of complex, high density, regions such as will be experienced near a divertor plate and in a radiative divertor, the behavior of these secondary species is likely to be crucial. The data sets also often are quite inadequate in their treatment of the possible contribution of impurities released from surfaces; for example Be released by erosion of the divertor plate. Thus, the data bases require supplementation either by extracting further information from the literature or by estimating cross sections by well established scaling relations.

A matter of particular interest to us is the influence of metastable species where cross sections are known to be orders of magnitude higher than that of the ground state. As an example drawn from our own experimental work, carbon ions from any high density ionization source are as much as 30% metastable [1] and these metastables exhibit charge transfer cross sections two orders of magnitude greater than the ground state [2] and dominate the behavior of any carbon ion flux. High densities of metastable components are likely to be present in any region containing impurities injected to promote radiative cooling, and the metastable components may dominate transport. Assessed data compendia have a very inadequate coverage of metastable collision events. It is imperative to perform sensitivity analyses to determine which secondary species are likely to be important and where further work is needed.

B. PROPOSED WORK

We propose first to assess the utility of the IAEA sponsored data bases by importing them through the ALADDIN format into our neutral transport code. A first scenario will be to consider H2 for the injected gas in the divertor region; for this case data coverage should be rather complete. We shall identify gaps in the data and attempt to cover them by reference to recent data compendia such as those by Tawara [3] for electrons and by Phelps [4] for ions. This first importing of information should provide us with the primary collisional processes.

The neutral transport code will calculate the formation of secondary products such as photons, metastables, slow ions and electrons whose transport and further reactions must then be included. Of particular importance will be molecular recombination and rearrangement events and processes involving metastable species, all of which will exhibit very high cross sections at low energies.

With the combination of primary and secondary processes in the neutral transport code we shall perform a sensitivity analysis to evaluate the importance of each mechanism and whether the existing limits of accuracy are adequate for prediction of the behavior in the divertor and separatrix regions.

The procedure can then be repeated for impurity species such as N_2 and Ar which might be deliberately injected to promote radiative cooling. Also of great interest will be the contribution due to atoms of the divertor plate material ejected by collisional erosion. An adequate data base exists for the primary and many secondary processes related to common gases (N_2 and Ar) and to carbon. But for a case such as Be, a candidate divertor plate material, there is little or no information and cross sections will need to be estimated from scaling relations. Both C and Be have important metastable states for which cross sections will be very large. An important task will again be the sensitivity analysis to determine which processes are most important and also the accuracy with which the input data needs to be specified.

A significant purpose of the work is to identify areas where existing data bases are inadequate and to encourage the IAEA data collection program to set up cooperative programs to provide the needed information.

C. EFFORT, TIME AND BUDGET

The proposed program draws heavily on the experience of Dr. Thomas in preparation of evaluated data compendia for the ORNL and IAEA data centers. It is seen as a continuing effort in providing the input information for the modeling codes. We envisage employing one PhD thesis student, and Dr. Thomas will devote approximately 15% of full time to this project. Support of this effort will require about $50K per year, allowing for fringe, overhead and travel.

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V. SUPERCODE DEVELOPMENT & ANALYSIS

We propose to continue our participation in the US ITER Systems and Operational Studies Task Area, providing support for the development and use of the SUPERCODE, the new 1-1/2-D US systems and operational code. Specific areas in which our group can make unique contributions, both in the development of the code and in using it to analyze various ITER operating scenarios, are proposed.

A. BACKGROUND

Georgia Tech has been participating in the development of the SUPERCODE, the fast, 1-1/2-D, tokamak physics and engineering simulation code for ITER [1], since its inception in 1990. We have provided models and routines for the self-consistent, profile-dependent evaluation of neutral beam deposition, heating and current drive [2], the implementation of theory-based transport models including the Rebut Critical Electron Temperature Gradient model as well as a diagonal neoclassical model, the calculation of the bootstrap current, the accurate calculation of the peak neutron wall load, the calculation of the heating profiles from ICRH and the resulting fast wave driven current, and a pellet fueling model (modules *Beams, Boots, NDWallLoad, ICRH, Pellets,* and several routines in the *Transport* module). These routines (which have been benchmarked against calculations performed with more sophisticated codes with excellent agreement) greatly enhance the capabilities of the SUPERCODE and extend its usefulness as a modern systems analysis tool for ITER and other future tokamak reactors.

At the same time, we have been using the SUPERCODE to carry out several system and optimization studies for ITER[3-6]. Some of these studies were performed at the request of different groups within the US ITER Home Team, such as the Neutral Beam and the Magnet task area groups. This is consistent with one of the missions of the US System and Operational Studies task area as a service organization for the US Home Team structure.

Two of our major accomplishments this year have been the implementation of the new Rebut critical electron temperature gradient transport model in the SUPERCODE, and the modeling of the operational performance of ITER-R with consistent 1-D radial transport [7]. The implications of this model on the ignition performance of ITER-R and the significant differences with predictions based on 0-D modeling and using the ITER-P scaling law have been reported to the ITER community.

B. PROPOSED WORK

While the exact needs of the ITER EDA are not known in detail yet, we expect to continue providing support to the US Home Team and the Joint Central Team (JCT) on an "as-requested" basis. We believe that the strength of the SUPERCODE in integrating the essential features of physics performance, engineering models, design constraints as well as costing considerations, will make it an indispensable tool for both Home Team initiatives and JCT work.

Our group at Georgia Tech can make important contributions, both in the continuing development of the code and in using it to analyze specific scenarios of interest.

1. <u>Code Development</u>:

Specifically, in the area of code development, we propose to work on the following tasks:

a. Self-consistent MHD and current drive: By making the MHD equilibrium more consistent with the external and internal current sources, we can study current drive optimization and startup scenarios, as well as the effect of the current profile on the confinement properties.

b. ECH model: We will develop, benchmark, and install a profile-dependent ECH module for the calculation of heating and current drive due to the launching of waves in the electron cyclotron range of frequencies. This module will enhance the capability of the SUPERCODE for heating and current drive simulations, complementing the existing neutral beam and ICRH modules.

c. Fueling: We have just completed the development of a pellet fueling module. We will add the capability for gas puffing fueling by adopting a neutral transport model based on a semi-analytic solution of the integral transport equation for edge-originated neutrals.

d. Impurity Radiation: Currently, impurity radiation is included in the SUPERCODE using simple parametric fits that were developed during the ITER CDA [8]. However, a more accurate impurity model will be needed in order to investigate operating scenarios with enhanced impurity radiation, resulting from either externally introduced or wall-originated impurities. We will use our considerable expertise in this area (gained from our studies of radiative edge operating scenarios for ITER using a time-dependent 1-1/2-D transport code coupled with multi charge state impurity transport routines [9]) to develop simpler models appropriate for a systems code. These models would contain most of the essential physics and could be based on the transport of a few important charge states, or on parametric fits that would be derived from the more accurate full impurity transport simulations and which would be valid in the parameter range of interest.

It is also worth mentioning here that most of these modules will be imported into the new free-boundary MHD and plasma transport code, CORSICA, which is currently under development at LLNL, and which is expected to play an important role during the ITER EDA.

2. Analysis

We will also be using the SUPERCODE to perform system analysis studies for ITER. The exact nature of these studies will depend on the needs of the project, but it is expected to include operational scenario modeling for ignited or near-ignited operating points under inductive operation, steady-state, current-driven performance with NB, IC fast wave or EC current drive, and other studies on cost and performance tradeoffs. The SUPERCODE is also expected to play an important role in the study of Burn Control, which has emerged as an important safety issue for ITER. While a steady state code, its ability to efficiently provide us with a mapping of the operating space and with a global picture of the thermal stability properties of potential operating points makes it a very useful tool for the initial stage of the burn control studies.

In addition, we will take the lead in the study of the effect of the current density profile on confinement. Recent experimental results from DIII-D and other tokamaks [10], indicate that improved confinement and stability can be obtained through the modification of the current profile. This suggests that an optimum current profile may exist which, for a given confinement model, could increase the performance and reduce the size and cost of the machine. We believe that the advanced physics models of the SUPERCODE, combined with its computational speed and its engineering and costing modules, make it the ideal tool for such a study.

C. EFFORT, TIME AND BUDGET

The proposed work consists of a continuing effort by Dr. Mandrekas, support by graduate students. Dr. Mandrekas will devote 75% of his time to this effort, and graduate students will assist him at a level of effort corresponding to one man-year. The required support is about $90K/year, including fringe and overhead.

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VI. BURN CONTROL

The demonstration of the controllability of the thermonuclear burn conditions for a several GW power producing reactor such as ITER is expected to be an important issue during the Engineering Design Activity (EDA), from both safety and design heat flux considerations. Burn control (which generally includes operating point control, burn stability control and control of off-normal transient phenomena) is an area that encompasses physics and technology, as well as licensing and regulatory requirements. We propose to study burn control scenarios for the ITER EDA, taking advantage of our considerable experience and existing computational capability in this area, having been one of the principal participants in the US Burn Control Studies group during the ITER CDA.

A. BACKGROUND

Examination of the thermal stability properties of candidate operating points for a reactor like ITER reveals that many potentially attractive operating points (in terms of good divertor performance conditions, proximity to the beta limit, etc.) can be thermally unstable. The thermal stability properties of an operating point depend, among other factors, on the confinement scaling or energy transport model assumptions. Some of these models predict the existence of operating points that are inherently thermally stable, and operation at such points would certainly be highly desirable, it they exist. However, our present incomplete understanding of the physical mechanisms that are responsible for radial transport in tokamak plasmas and the uncertainty regarding operating conditions that may affect thermal stability (such as impurity content and alpha ash concentration in the plasma) make relying on the inherent stability of candidate operating points risky and incompatible with the high degree of safety desired in the design of ITER. Failure to control a thermal instability, and hence the power level of the reactor, can lead to excessive heat loads on the first wall and divertor components, as well as to other off-normal events such as disruptions triggered by the violation of beta or density limits in the plasma. The designer is faced with the requirement either of providing enough margin in the heat flux capability of the first wall and divertor to tolerate excessive off-normal heat loads and enough strength in the divertor to tolerate a large number of disruptions triggered by thermal runaways, or of providing an effective burn control system that can limit thermal runaways to an acceptable range. The first option leads to a prohibitively expensive, if not altogether unachievable, design. Therefore, the definition of a credible burn control scenario (along with the associated requirements on diagnostic and other technological systems) should be a high priority task during the early parts of the ITER EDA.

Burn Control was studied during the ITER CDA, having been one of the task areas of the U.S. Systems and Operating Studies group. Georgia Tech was one of the principal participating institutions during this study. We developed methodologies and computational tools to evaluate a large number of potential methods for the control of the thermonuclear burn conditions of ITER near thermally unstable operational points and to determine the technological requirements on the associated ITER hardware systems [1-5]. Our calculations indicated that operation of the ITER CDA machine at thermally unstable operating points was feasible using a variety of methods ranging from "standard" control methods (such as auxiliary power modulation for near-ignited points, modulation of the fueling rate for ignited points, injection of impurities, etc.) to more "advanced" ones such as control with modulation of the divertor pumping fraction [2]. We found that edge effects can be very important and may even contribute to passive stability[2]. We also deternined the technological requirements that each proposed control mechanism would impose on the ITER hardware components (e.g., maximum reserve power and minimum acceptable ramp rate of the heating system, reserve capacity of the fueling source,). A series of 1-1/2-D simulations that we performed [3] confirmed our 0-D predictions and also indicated that the response of the control system can be improved if use of spatially-resolved neutron flux measurements are made. The results of our work, along with those from the other U.S. participants, helped to define the recommendations for a primary and secondary control scheme for the CDA ITER device [5].

The computational tools that we used for this work include a 0-D transport code with advanced physics capabilities and control algorithms that we developed, and the WHIST 1-1/2-D transport code [6] for the spatially-dependent study of burn control scenarios. As part of our recent work on the study of impurity seeding scenarios for ITER [7-8], we have added new capabilities to the WHIST transport code. These include routines for the time-dependent transport of multi-charge state impurities within the core, as well as a simple but comprehensive SOL/divertor model. These upgrades allow us to study, in a self consistent way, the effects of impurities (wall-originated or externally introduced) on the evolution of the core plasma, as well as to assess the effects of transient phenomena on the divertor heat load. We are presently upgrading the SOL/divertor model in WHIST to included radiation, and will extend it to treat ions and electrons separately in the near future; and we are upgrading the MHD capability in WHIST by incorporating VMEC. At the same time, our 0-D code is being upgraded to a multi-region model, by adding coupled edge and divertor models to the present core model, for a better study of the effects of edge conditions on the dynamics of a burning plasma. The 0-D model provides a capability to perform a large number of control studies, while the 1-1/2D model provides the capability to study the coupled dynamics of the plasma core and the SOL/divertor in detail.

B. PROPOSED WORK

It is proposed to continue our burn stability control studies during the EDA phase of the ITER project. Particular emphasis will be placed on issues that are identified by the JCT as critical. We anticipate that these will be similar to those which were identified as critical during the ITER CDA Burn Control Studies. Such issues may include the identification of credible burn control schemes and the assesssment of the associated technological requirements and of the effect of physics uncertainities, the definition of the minimum diagnostic requirements for controllability, the identification of worst case transients, the study of the effect of perturbations introduced by sawteeth oscillations and pellet injection on thermal stability, and the identification of phenomena and processes that can contribute to the inherent, passive stability of the system. Attention will also be given to thermal instabilities triggered by density fluctuations, a recent concern of the JCT. Such fluctuations (which earlier studies [9] have shown to give rise to distinct modes for certain confinement scalings) can be caused by desorption of fuel from the first wall of the device due to an increase in its temperature. The impurity influx that will most certainly accompany the fuel flux, should also be taken into account in the analysis of the response of the system.

We believe that our advanced computational capabilities make us qualified, perhaps uniquely so at this time, to study in detail any of these burn control problems. The impurity transport option that we added to the WHIST 1-1/2-D transport code will be especially useful for modelling scenarios involving wall-originated or externally introduced impurities and also for the simulation of off-normal operation, while our divertor and SOL model will give us an estimate of the effect that edge plasma conditions can have on the evolution of the core plasma during transients. Our computational tools will also allow us to examine edge phenomena control schemes that are based on physics that is currently less well understood (but with a rapidly expanding database) and which hold the promise of reducing the technological requirements and cost of the control system. Such schemes will be based on mechanisms that can be affected in the edge region and which interactively influence and control the core thermonuclear burn [10].

C. EFFORT, TIME & BUDGET

We envision that the US Burn Control effort in support of ITER would be of a multi-institutional nature, would be an ongoing activity and would be carried out at a level dictated by the urgency assigned to the task by the JCT. We believe that a fairly substantial effort early in the EDA would be wise.

We propose to involve a graduate student who is doing his Ph.D. research in this area 100%, Dr. Mandrekas 10% and Dr. Stacey 5% in the specific activities described above. The required support is about $50K/year, including fringe and overhead. (In addition to this proposed level of effort, we plan to propose continuation of our participation in the SUPERCODE activity, some part of which might naturally be part of the US Burn Control activity.) If necessary, this level of effort could be increased by the assignment of a Postdoctoral Research Scientist.

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Proposal To The
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August 13, 1993

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Principal Investigator

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W. M. Stacey, Jr., Director
Fusion Research Center

Date: 8-13-93

SUMMARY

We propose to expand our involvement in the US Edge Physics effort in support of the ITER Project. We have identified four specific tasks in the areas of **ITER DIVERTOR ANALYSIS** which are important to ITER and in which we have a special capability. These areas are: 1) implementation of a DEGAS-compatible collision-escape probability neutral particle transport model; 2) characterization studies of viscous forces and implementation of a full viscosity formalism in UEDGE; 3) coupled plasma core-plasma edge-SOL-divertor analysis of radiative electron cooling; and 4) comparative analysis of atomic and molecular effects in the presheath region.

We propose to continue our activities in support of 5) **SUPERCODE DEVELOPMENT & ANALYSIS**. This includes continued module development and application of the code in support of design analyses.

We propose to expand our activity in 6) **BURN CONTROL**. This will utilize our highly developed capabilities in this area to identify burn control mechanisms and scenarios for ITER.

I. NEUTRAL PARTICLE TRANSPORT

A new computational model for neutral particle transport in the divertor and scrape-off layer is under development. This model is based on precomputed transmission and escape probabilities, which should lead to a model with reasonable accuracy and computational economy. Funding for development and testing of the model has been proposed separately to DOE/OFE. ITER is supporting the adaptation of the model to the geometric representation used in DEGAS, so that it can be incorporated as a computational economical neutral transport option in DEGAS, and it is proposed that this support be continued.

A. BACKGROUND

Neutral particle transport can be calculated to within the accuracy imposed by uncertainties in the data for atomic and molecular processes by Monte Carlo, provided that a sufficient number of particle histories are followed to obtain "good" statistics. However, the computational time required for such calculations precludes their use on a routine basis.

There are certain limitations to the deterministic neutral transport methods that have been used for plasma edge calculations, as discussed in Ref. [1]. Diffusion theory, perhaps the most used method, is of limited accuracy in many edge plasma situations where the assumption of linear anisotropy in the angular distribution can not be justified (e.g. near a material wall or an interface across which the neutral flow is highly unidirectional). Extensions to higher order spherical harmonics is straightforward in 1D, but becomes complex in 2D. The discrete ordinates method, which has been highly developed in 2D for neutron transport, has only been formulated in regular (e.g. rectangular, cylindrical) geometries, which are not suitable for the representation of plasma edge regions. Integral transport models are economical when ionization or other "removal" processes dominate charge-exchange or other "scattering" processes, but become quite complex and time-consuming when multiple "scattering" events must be followed.

The computational method that we are developing may be considered as a variant of integral transport theory. Uncollided transmission of neutral particles across a region from one bounding surface to another is calculated by integral transport theory and can be precomputed as transmission probabilities which depend only on the mean-free-path of the region. The transmission of neutral particles across a region from one bounding surface to another via a series of charge-exchange or other "scattering" events, which is the computational intense aspect of an integral transport model, is replaced by the calculation of escape probabilities based on chord distribution theory, which leads to simple limiting expressions that can be used to formulate a simple rational approximation.

B. PROPOSED WORK

We have proposed to DOE/OFE to undertake the development and testing of the transmission-escape probabilities method for neutral particle transport, and are undertaking this development on a limited scale, pending receipt of support therefor.

We propose to ITER to continue our work to adapt the transmission-escape probabilities model to the DEGAS geometry package. The objective is a DEGAS - compatible module which can be used as a computationally economical neutral option by codes with can interface with DEGAS. We further propose to develop a code for processing the atomic, molecular and surface data used by DEGAS into the form needed in the transmission-escape probabilities model.

C. EFFORT, TIME & BUDGET

We anticipate that the development of a DEGAS-compatible computational module and the associated data processing code will be carried out over a period of about two years, in parallel with the development and testing of the method. Initial versions would be available for testing during the first year.

The proposed effort is intended to require 5% of the Dr. Stacey's time, 5% of Dr. Mandrekas's time, and 50% of a Post-Doc. Support of this effort will require about $50K per year, allowing for fringe, overhead and travel.

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II. VISCOSITY

It has been established from order-of-magnitude ordering arguments that viscosity produces order unity effects on the calculated flow fields in tokamak scrape-off layers and divertor channels and on the predicted peaking of the energy transported to the divertor collector plate; yet a full treatment of viscosity is not commonly included in calculations of these quantities. It is proposed to: 1) quantitatively characterize the effect of viscous forces that would be predicted throughout the scrape-off layer and divertor channel of existing tokamaks and of ITER, based on a recently developed formalism; and 2) incorporate the recently-developed viscosity formalism in the 2D code UEDGE.

A. BACKGROUND

The calculation of the flow of plasma ions in the scrape-off layer and divertor of tokamaks is a subject that is receiving increased attention because of its importance to the prediction of energy transported to the divertor collector plates and because of the apparent relationship between shear in the flow field and the L-H transition in energy confinement regime. Most calculations of the flows are based on fluid models and treat the viscosity approximately with a parallel term and an anomalous radial term (e.g. Refs.1-6). Such a reduced treatment of viscosity is perhaps justified in the plasma core, where the relatively long radial gradient scale lengths of the pressure and velocity distributions generally result in the viscosity being smaller than other terms in the equations. However, in the scrape-off layer(and in the plasma edge just inside the separatrix, as well) there is ample theoretical [7] and experimental [8-11] evidence that the radial gradient scale lengths of the pressure and velocity are small, of order of the gyroradius. With such a small radial gradient scale length, the viscous force and energy flux terms become comparable with the pressure and other leading order terms in the fluid equations, and omission of important viscous flow cross-derivative terms can introduce significant error.

The effects of viscous forces and energy fluxes on the nature of the fluid equations and on the prediction of radial peaking in the energy flux incident on the divertor collector plate, in the small-radial-gradient-scale-length (SRGSL) ordering, has been investigated theoretically [12]. It was found that the SRGSL ordering raises viscous terms to leading order and fundamentally alters the character of the fluid equations. A viscous drift term of the same order as the diamagnetic and ExB drifts obtains. Important viscous forces result from cross-derivatives of the flow field and can not be modeled by a purely parallel plus anomalous radial representation of viscosity. Order-of-magnitude estimates indicate that viscous-driven radial energy fluxes in the scrape-off layer and divertor channel have an order unity effect in reducing the radial peaking of energy fluxes that are transported along field lines to divertor collector plates. Although no studies have been made, yet it seems intuitive that viscous forces of this magnitude would also greatly affect the Ohm's law governing plasma currents in the scrape-off layer and divertor. All of this has profound implications for both the interpretation of present experiments using fluid code calculations , which treat viscosity approximately, and for the prediction of power peaking on the divertor collector plate in ITER (and TPX) using such codes.

The previous study [12] establishes, from order-of-magnitude estimates, that viscous forces and energy fluxes can be important within the scrape-off layer and divertor channel of tokamaks. It should be possible to use the same formalism in conjunction with existing 2D fluid calculations of energy and particle flows to quantitatively characterize where viscous terms are important within the scrape-off layer and divertor channel and to establish specific criteria for the inclusion or omission of viscous terms. Such a characterization would quantitatively establish the importance of omitted viscous effects in calculations of particle and energy flows in the divertor and scrape-off layer of present experiments and future devices. Since the viscous terms would significantly complicate the calculation and may not be needed everywhere in the scrape-off layer and divertor, such a characterization and associated criteria would also be useful in guiding the modification of existing codes to include the most important viscous effects. Such a study would also provide a quantitative estimate of how the results of present calculations of flows would be changed by the inclusion of viscous terms and of how these viscous changes would alter phenomena such as the peaking in the energy flux incident on the divertor collector plate. Given the urgency of resolving the divertor energy loading issue for ongoing designs of ITER (and TPX), we propose to use the formalism of Ref [12] to perform a calculational study to characterize viscous forces and their effects in the scrape-off layer and divertor channel of existing and planned tokamaks, with the objectives of understanding the magnitude and character of the changes that would result in existing fluid calculations if viscous effects were incorporated and of establishing criteria for inclusion of viscous effects. We will also characterize the effect of viscous forces on the plasma currents in the scrape-off layer and divertor, using a formalism which we now are developing separately. One prime intention of such a study is to provide a timely, quantitative estimate of the reduction in the predicted peak energy flux to the divertor collector plate that would result from the inclusion of viscous effects in 2D fluid codes.

We further propose to implement the viscous formalism in an existing 2D fluid code. We will then repeat the above characterization studies, with the intent of providing a quantitative understanding of the influence of viscous effects on particle and energy flows and on currents in the scrape-off layer and divertor channel and on reduction in the radial peaking of the power flow to the divertor plates.

The previous study [12] was carried out within the framework of fluid theory. Questions have been raised [13] about the validity of the conventional derivation of fluid theory from kinetic theory for ions in the scrape-off layer and divertor channel. We further note the need to rederive the fluid viscosity formalism from kinetic theory for a multi-ion-species plasma that is interacting with neutral species. It is likely that such a new theory will affect the calculated values of viscosity coefficients, possible that it will alter the mathematical structure of the viscous forces, but unlikely that it will change the predicted order of magnitude of the viscous effects. Thus, we believe that the proposed study will provide significant insights which may be altered in detail but not in magnitude by future developments in the theory. (We are separately developing, from kinetic theory, a fluid representation of viscosity in a multi-species plasma in the presence of an interacting neutral species, with the objective of providing a viscosity formalism and a general fluid formalism that are appropriate for modeling plasma ions, impurities and electrons in the scrape-off layer and divertor channel of tokamaks).

B. PROPOSED WORK

Two separate, but related, activities are proposed: 1) quantitative characterization of viscous forces that would be predicted throughout the scrape-off layer and divertor channel of existing and future tokamaks; and 2) implementation of the viscous formalism in an existing 2D fluid code.

B.1 Quantitative Characterization of Viscous Forces

Two-dimensional calculations of flow velocities throughout the scrape-off layer and divertor channel of existing tokamaks and ITER designs will be used to evaluate the magnitude of the viscous drift, viscous forces and viscous energy fluxes defined in Ref. [12]. Estimates of how the calculated flow velocities and currents would change, of how much the predicted peaking of the energy flux on the collector plate will change, and of other quantities of interest will then be made. The 2D flow velocities will be calculated with existing codes, and the results of other groups will be used when readily available. We plan to use the 2D code UEDGE, which is available at NERSC, for this purpose. Calculations for existing experiments (e.g. DIII-D, ALCATOR C-Mod) and ITER will be made, as necessary to characterize the various aspects of the problem.

Guided by the above calculations, model calculations will be performed to quantitatively characterize the importance of the viscous terms defined in Ref. [12] and to develop criteria for their inclusion in fluid computations. Simplified geometries that are representative of various aspects of the flow problem in tokamak scrape-off layers and divertor channels will be modeled.

At a later time, when the viscous representation is incorporated into UEDGE, we will utilize this code to confirm and extend the above results. Changes in flow velocities, currents and the peaking of the energy flux on the divertor collector plate due to viscous effects will be calculated directly. The criteria for inclusion of viscous effects will be checked in realistic geometries and modified as required.

B.2 Implementation of Viscous Formalism in UEDGE

The existing 2D fluid codes that have been developed to study the scrape-off layer and divertor channel of tokamaks (e.g. [1-6]) are based on a variety of coordinate systems and representations of the fluid equations. The viscous representation depends on the choice of representation of the fluid equations and upon the coordinate system that is adopted; thus the proper viscous representation for each code probably differs from either of the representations given in Ref. [12]. We propose to develop a representation appropriate for UEDGE and to implement this in that code.

C. EFFORT, TIME AND BUDGET

Because of the PI's rather extensive previous work (see Refs. 12 and 14) in the area of viscosity, the proposed work can be carried out rather expeditiously, without the necessity of a lengthy review and startup process. It is intended that the characterization study B.1 be carried out by a Post-Doc working under the direct supervision of the PI. Initial results should be available within 3-6 months of initiation of the project, and it should be possible to conclude and document a comprehensive study within another 18 months. The work on implementing the viscous formalism in UEDGE will be ongoing over the two years of the proposed project.

The proposed effort is intended to require 5% of the Dr. Stacey's time, 5% of Dr. Mandrekas's time, and 50% of a Post-Doc. Support of this effort will require about $50K per year, allowing for fringe, overhead and travel.

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III. RADIATIVE ELECTRON COOLING

We propose to use a coupled core/SOL-divertor transport code package that we have partially assembled to investigate the possibility of radiatively cooling the electrons, on both sides of the separatrix, so as to reduce the electron component of the power flow to the divertor collector plate. The analysis will include an evaluation of the efficacy of methods for preventing impurities in the edge plasma from penetrating to the core plasma.

A. BACKGROUND

Reduction of the power flow to the divertor collector plate, in particular the highly peaked electron component, is a major feasibility issue for ITER (and for TPX and other future tokamaks). While there appear to be possible solutions for reducing the ion power flux to the divertor [1], feasible means for reducing the electron power flux remain to be identified. Since the electrons apparently transport energy rapidly to the divertor collector plate along a rather narrow channel just outside the separatrix and do not collisionally equilibrate with the ions, it is necessary to find a mechanism which cools the electrons directly.

Radiative cooling of the electrons by impurities is a possible mechanism for reducing the electron component of the power flux to the divertor plate. However, it is not clear that radiative cooling can overcome the large parallel electron transport in the scrape-off layer and divertor. The effective radiative region in the divertor channel will be confined to a rather narrow electron temperature range, hence spatial region, unless impurity ions in low ionization states can be transported rapidly from the vicinity of the collector plate upstream into the radiative region, which is somewhat at odds with the objective of entraining impurities within the divertor channel. This suggests that radiative cooling of electrons before they cross the separatrix, while they are confined in the plasma edge region, might be a possible solution to the divertor energy flux problem. However, such a solution is only useful if the impurities can be confined to the plasma edge region and prevented from diffusing into the plasma core region. There is recent experimental evidence [2] from DIII-D that the electrons can be radiatively cooled in the plasma edge/SOL by MARFEs, and this has motivated plans to experimentally study radiatively cooling electrons by impurity injection inside the separatrix--just the concept proposed here. There is evidence [3] that impurities can be inhibited from diffusing into the plasma core by a positive radial electric field in the edge plasma.

B. PROPOSED WORK

We propose to analyze the possibility of radiatively cooling plasma electrons, both before and after they cross the separatrix. The emphasis will be on cooling with impurities that are trapped in the plasma edge region inside the separatrix, but we will also take into account cooling by impurity radiation in the scrape-off layer and divertor channel.

We will use the 1-1/2D plasma transport code WHIST [4], which has been operational at Georgia Tech during the last few years and has been used extensively for our ITER burn control studies [5]. We have recently modified WHIST to include multi-charge-state impurity transport, an improved MHD equilibrium model (Hirshman's VMEC code), and a simple but comprehensive scrape-off layer and divertor model. This advanced computational capability allows for a more self-consistent treatment of the effect of enhanced edge radiation on the power balance of the coupled core plasma-edge plasma-scrape off layer-divertor; it has been used already in the evaluation of impurity seeding scenarios for ITER [6]. We are currently extending our single-fluid 2-point model of the scrape-off layer and divertor to treat electron and ion energy transport separately, in order to be able to model explicitly the different energy transport processes along the magnetic field lines for the ion and electron channels. We are in the process of incorporating impurity radiation in the scrape-off layer and divertor, using a simple radiation model similar to that of McCracken and Pedgley [7] upgraded using a residence time correction to take into account non-coronal equilibrium effects. We also plan to incorporate an improved neutrals model to treat atomic and molecular effects more accurately. At a later stage, we plan to couple our multi-charge-state WHIST core transport code with a multi-charge-state 1D fluid code for the scrape-off layer and divertor (e.g. NEWT-1D [8]).

The analysis will initially consist of "injecting" impurities into the edge plasma inside of the separatrix, calculating their transport and radiative electron cooling with WHIST to obtain electron, ion and impurity particle fluxes and electron and ion energy fluxes into the SOL at the midplane, then using the 2-point SOL/divertor model to calculate the electron and ion power fluxes to the divertor collector plate. We will also calculate the impurity diffusion to and radiative cooling of the plasma core, with and without inhibiting mechanisms such as radial electric field modification by NBI-driven rotation in the edge plasma region. We will attempt to model the impurity "injection" from the SOL consistently, but this aspect can be made fully consistent only when we replace the 2-point SOL/divertor model with a 1D fluid code with impurity transport at a later stage.

We will study various impurity species, including intrinsic low-Z impurities (Be) and externally supplied intermediate-Z impurities. We will also identify and study a variety of methods for modifying edge impurity transport by modification of the radial electric field and otherwise. Current models of the ITER plasma and edge conditions will be used in the studies. The overall objective of the analyses will be to assess if impurities can be used to radiatively cool electrons in the plasma edge before they cross the separatrix in order to reduce the electron component of the power flux on the divertor collector plate, without deleterious effect on the plasma core.

We also plan to analyze the impurity seeding experiments in DIII-D, which will provide confirmation of the computational model used for the ITER analyses. This effort will take place prior to or concurrent with the ITER analyses, depending on the timing of the experiments. Preliminary discussions with Stambaugh to this end have been held.

C. EFFORT, TIME AND BUDGET

This work will be carried out over about 2 years as Ph.D. thesis research by Mr. Heping He, who has already spent about that amount of time becoming familiar with the area and modifying the WHIST code. Supervision of the work will be done by Drs. Stacey and Mandrekas, involving about 5% of their time. Support of this effort will require about $35,000 per year for 2 years, allowing for fringe, overhead and travel.

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IV. ATOMIC AND MOLECULAR MECHANISMS & DATA IN THE SCRAPE-OFF LAYER AND DIVERTOR

We propose to perform a comparative analysis of cross sections for atomic and molecular collision processes that could be important for analysis of radiative cooling in the scrape-off layer and divertor regions. In part, we shall use existing critically evaluated data bases using the ALADDIN data transfer format recommended by the IAEA. We anticipate that the compendia will inadequately cover processes involving secondary species created by ionization and excitation. An analysis of the sensitivity of the model prediction to the input data base will identify such inadequacies which in turn should be a major focus for further coordinating activities of the IAEA in support of ITER. Where appropriate, we shall supplement the existing data bases with cross section estimates based on established scaling relations.

A. BACKGROUND

Neutral and fluid transport codes require, as an input, cross section information for the various collisional processes. As far as possible, one should utilize critically assessed data bases which are approved by experts in the atomic collision field and readily available to all modeling groups. The IAEA Atomic and Molecular Data Unit has been responsible for coordinating the provision of data bases for Fusion; Dr. Thomas has contributed to a number of these compendia through the IAEA and through the ORNL data center. Surprisingly, these extensive, assessed data tabulations have only rarely been incorporated into modeling codes. We plan to use a relatively simple, 1D, multigroup neutral transport code to test the completeness of the available data bases and the utility of the ALADDIN data transfer format adopted by the IAEA. Moreover the code will permit us to perform a sensitivity analysis to determine which processes dominate the behavior of the plasma in the edge and divertor; this will lead to identification of processes where collisional information is inadequate and where further work should be coordinated by the IAEA.

Energy degradation of electrons in the SOL occur first by inelastic, ionization and excitation events which exhibit peak cross sections in the region of 100's eV, followed by elastic events as energy declines; these may be termed the primary events. But a satisfactory analysis must include the further transport of the secondary products of the initial events which will include ions, metastables and photons; recombination, molecular rearrangement and Penning ionization are likely to be the processes dominating transport of these secondary products.

The data bases provide an adequate coverage of the primary interactions of charged particles with fuel and common impurities. They are, however, rather weak in the coverage of transport of the secondary products. In the modeling of complex, high density, regions such as will be experienced near a divertor plate and in a radiative divertor, the behavior of these secondary species is likely to be crucial. The data sets also often are quite inadequate in their treatment of the possible contribution of impurities released from surfaces; for example Be released by erosion of the divertor plate. Thus, the data bases require supplementation either by extracting further information from the literature or by estimating cross sections by well established scaling relations.

A matter of particular interest to us is the influence of metastable species where cross sections are known to be orders of magnitude higher than that of the ground state. As an example drawn from our own experimental work, carbon ions from any high density ionization source are as much as 30% metastable [1] and these metastables exhibit charge transfer cross sections two orders of magnitude greater than the ground state [2] and dominate the behavior of any carbon ion flux. High densities of metastable components are likely to be present in any region containing impurities injected to promote radiative cooling, and the metastable components may dominate transport. Assessed data compendia have a very inadequate coverage of metastable collision events. It is imperative to perform sensitivity analyses to determine which secondary species are likely to be important and where further work is needed.

B. PROPOSED WORK

We propose first to assess the utility of the IAEA sponsored data bases by importing them through the ALADDIN format into our neutral transport code. A first scenario will be to consider H2 for the injected gas in the divertor region; for this case data coverage should be rather complete. We shall identify gaps in the data and attempt to cover them by reference to recent data compendia such as those by Tawara [3] for electrons and by Phelps [4] for ions. This first importing of information should provide us with the primary collisional processes.

The neutral transport code will calculate the formation of secondary products such as photons, metastables, slow ions and electrons whose transport and further reactions must then be included. Of particular importance will be molecular recombination and rearrangement events and processes involving metastable species, all of which will exhibit very high cross sections at low energies.

With the combination of primary and secondary processes in the neutral transport code we shall perform a sensitivity analysis to evaluate the importance of each mechanism and whether the existing limits of accuracy are adequate for prediction of the behavior in the divertor and separatrix regions.

The procedure can then be repeated for impurity species such as N_2 and Ar which might be deliberately injected to promote radiative cooling. Also of great interest will be the contribution due to atoms of the divertor plate material ejected by collisional erosion. An adequate data base exists for the primary and many secondary processes related to common gases (N_2 and Ar) and to carbon. But for a case such as Be, a candidate divertor plate material, there is little or no information and cross sections will need to be estimated from scaling relations. Both C and Be have important metastable states for which cross sections will be very large. An important task will again be the sensitivity analysis to determine which processes are most important and also the accuracy with which the input data needs to be specified.

A significant purpose of the work is to identify areas where existing data bases are inadequate and to encourage the IAEA data collection program to set up cooperative programs to provide the needed information.

C. EFFORT, TIME AND BUDGET

The proposed program draws heavily on the experience of Dr. Thomas in preparation of evaluated data compendia for the ORNL and IAEA data centers. It is seen as a continuing effort in providing the input information for the modeling codes. We envisage employing one PhD thesis student, and Dr. Thomas will devote approximately 15% of full time to this project. Support of this effort will require about $50K per year, allowing for fringe, overhead and travel.

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V. SUPERCODE DEVELOPMENT & ANALYSIS

We propose to continue our participation in the US ITER Systems and Operational Studies Task Area, providing support for the development and use of the SUPERCODE, the new 1-1/2-D US systems and operational code. Specific areas in which our group can make unique contributions, both in the development of the code and in using it to analyze various ITER operating scenarios, are proposed.

A. BACKGROUND

Georgia Tech has been participating in the development of the SUPERCODE, the fast, 1-1/2-D, tokamak physics and engineering simulation code for ITER [1], since its inception in 1990. We have provided models and routines for the self-consistent, profile-dependent evaluation of neutral beam deposition, heating and current drive [2], the implementation of theory-based transport models including the Rebut Critical Electron Temperature Gradient model as well as a diagonal neoclassical model, the calculation of the bootstrap current, the accurate calculation of the peak neutron wall load, the calculation of the heating profiles from ICRH and the resulting fast wave driven current, and a pellet fueling model (modules *Beams, Boots, NDWallLoad, ICRH, Pellets*, and several routines in the *Transport* module). These routines (which have been benchmarked against calculations performed with more sophisticated codes with excellent agreement) greatly enhance the capabilities of the SUPERCODE and extend its usefulness as a modern systems analysis tool for ITER and other future tokamak reactors.

At the same time, we have been using the SUPERCODE to carry out several system and optimization studies for ITER[3-6]. Some of these studies were performed at the request of different groups within the US ITER Home Team, such as the Neutral Beam and the Magnet task area groups. This is consistent with one of the missions of the US System and Operational Studies task area as a service organization for the US Home Team structure.

Two of our major accomplishments this year have been the implementation of the new Rebut critical electron temperature gradient transport model in the SUPERCODE, and the modeling of the operational performance of ITER-R with consistent 1-D radial transport [7]. The implications of this model on the ignition performance of ITER-R and the significant differences with predictions based on 0-D modeling and using the ITER-P scaling law have been reported to the ITER community.

B. PROPOSED WORK

While the exact needs of the ITER EDA are not known in detail yet, we expect to continue providing support to the US Home Team and the Joint Central Team (JCT) on an "as-requested" basis. We believe that the strength of the SUPERCODE in integrating the essential features of physics performance, engineering models, design constraints as well as costing considerations, will make it an indispensable tool for both Home Team initiatives and JCT work.

Our group at Georgia Tech can make important contributions, both in the continuing development of the code and in using it to analyze specific scenarios of interest.

1. <u>Code Development</u>:

Specifically, in the area of code development, we propose to work on the following tasks:

a. Self-consistent MHD and current drive: By making the MHD equilibrium more consistent with the external and internal current sources, we can study current drive optimization and startup scenarios, as well as the effect of the current profile on the confinement properties.

b. ECH model: We will develop, benchmark, and install a profile-dependent ECH module for the calculation of heating and current drive due to the launching of waves in the electron cyclotron range of frequencies. This module will enhance the capability of the SUPERCODE for heating and current drive simulations, complementing the existing neutral beam and ICRH modules.

c. Fueling: We have just completed the development of a pellet fueling module. We will add the capability for gas puffing fueling by adopting a neutral transport model based on a semi-analytic solution of the integral transport equation for edge-originated neutrals.

d. Impurity Radiation: Currently, impurity radiation is included in the SUPERCODE using simple parametric fits that were developed during the ITER CDA [8]. However, a more accurate impurity model will be needed in order to investigate operating scenarios with enhanced impurity radiation, resulting from either externally introduced or wall-originated impurities. We will use our considerable expertise in this area (gained from our studies of radiative edge operating scenarios for ITER using a time-dependent 1-1/2-D transport code coupled with multi charge state impurity transport routines [9]) to develop simpler models appropriate for a systems code. These models would contain most of the essential physics and could be based on the transport of a few important charge states, or on parametric fits that would be derived from the more accurate full impurity transport simulations and which would be valid in the parameter range of interest.

It is also worth mentioning here that most of these modules will be imported into the new free-boundary MHD and plasma transport code, CORSICA, which is currently under development at LLNL, and which is expected to play an important role during the ITER EDA.

2. Analysis

We will also be using the SUPERCODE to perform system analysis studies for ITER. The exact nature of these studies will depend on the needs of the project, but it is expected to include operational scenario modeling for ignited or near-ignited operating points under inductive operation, steady-state, current-driven performance with NB, IC fast wave or EC current drive, and other studies on cost and performance tradeoffs. The SUPERCODE is also expected to play an important role in the study of Burn Control, which has emerged as an important safety issue for ITER. While a steady state code, its ability to efficiently provide us with a mapping of the operating space and with a global picture of the thermal stability properties of potential operating points makes it a very useful tool for the initial stage of the burn control studies.

In addition, we will take the lead in the study of the effect of the current density profile on confinement. Recent experimental results from DIII-D and other tokamaks [10], indicate that improved confinement and stability can be obtained through the modification of the current profile. This suggests that an optimum current profile may exist which, for a given confinement model, could increase the performance and reduce the size and cost of the machine. We believe that the advanced physics models of the SUPERCODE, combined with its computational speed and its engineering and costing modules, make it the ideal tool for such a study.

C. EFFORT, TIME AND BUDGET

The proposed work consists of a continuing effort by Dr. Mandrekas, support by graduate students. Dr. Mandrekas will devote 75% of his time to this effort, and graduate students will assist him at a level of effort corresponding to one man-year. The required support is about $90K/year, including fringe and overhead.

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VI. BURN CONTROL

The demonstration of the controllability of the thermonuclear burn conditions for a several GW power producing reactor such as ITER is expected to be an important issue during the Engineering Design Activity (EDA), from both safety and design heat flux considerations. Burn control (which generally includes operating point control, burn stability control and control of off-normal transient phenomena) is an area that encompasses physics and technology, as well as licensing and regulatory requirements. We propose to study burn control scenarios for the ITER EDA, taking advantage of our considerable experience and existing computational capability in this area, having been one of the principal participants in the US Burn Control Studies group during the ITER CDA.

A. BACKGROUND

Examination of the thermal stability properties of candidate operating points for a reactor like ITER reveals that many potentially attractive operating points (in terms of good divertor performance conditions, proximity to the beta limit, etc.) can be thermally unstable. The thermal stability properties of an operating point depend, among other factors, on the confinement scaling or energy transport model assumptions. Some of these models predict the existence of operating points that are inherently thermally stable, and operation at such points would certainly be highly desirable, it they exist. However, our present incomplete understanding of the physical mechanisms that are responsible for radial transport in tokamak plasmas and the uncertainty regarding operating conditions that may affect thermal stability (such as impurity content and alpha ash concentration in the plasma) make relying on the inherent stability of candidate operating points risky and incompatible with the high degree of safety desired in the design of ITER. Failure to control a thermal instability, and hence the power level of the reactor, can lead to excessive heat loads on the first wall and divertor components, as well as to other off-normal events such as disruptions triggered by the violation of beta or density limits in the plasma. The designer is faced with the requirement either of providing enough margin in the heat flux capability of the first wall and divertor to tolerate excessive off-normal heat loads and enough strength in the divertor to tolerate a large number of disruptions triggered by thermal runaways, or of providing an effective burn control system that can limit thermal runaways to an acceptable range. The first option leads to a prohibitively expensive, if not altogether unachievable, design. Therefore, the definition of a credible burn control scenario (along with the associated requirements on diagnostic and other technological systems) should be a high priority task during the early parts of the ITER EDA.

Burn Control was studied during the ITER CDA, having been one of the task areas of the U.S. Systems and Operating Studies group. Georgia Tech was one of the principal participating institutions during this study. We developed methodologies and computational tools to evaluate a large number of potential methods for the control of the thermonuclear burn conditions of ITER near thermally unstable operational points and to determine the technological requirements on the associated ITER hardware systems [1-5]. Our calculations indicated that operation of the ITER CDA machine at thermally unstable operating points was feasible using a variety of methods ranging from "standard" control methods (such as auxiliary power modulation for near-ignited points, modulation of the fueling rate for ignited points, injection of impurities, etc.) to more "advanced" ones such as control with modulation of the divertor pumping fraction [2]. We found that edge effects can be very important and may even contribute to passive stability[2]. We also determined the technological requirements that each proposed control mechanism would impose on the ITER hardware components (e.g., maximum reserve power and minimum acceptable ramp rate of the heating system, reserve capacity of the fueling source,). A series of 1-1/2-D simulations that we performed [3] confirmed our 0-D predictions and also indicated that the response of the control system can be improved if use of spatially-resolved neutron flux measurements are made. The results of our work, along with those from the other U.S. participants, helped to define the recommendations for a primary and secondary control scheme for the CDA ITER device [5].

The computational tools that we used for this work include a 0-D transport code with advanced physics capabilities and control algorithms that we developed, and the WHIST 1-1/2-D transport code [6] for the spatially-dependent study of burn control scenarios. As part of our recent work on the study of impurity seeding scenarios for ITER [7-8], we have added new capabilities to the WHIST transport code. These include routines for the time-dependent transport of multi-charge state impurities within the core, as well as a simple but comprehensive SOL/divertor model. These upgrades allow us to study, in a self consistent way, the effects of impurities (wall-originated or externally introduced) on the evolution of the core plasma, as well as to assess the effects of transient phenomena on the divertor heat load. We are presently upgrading the SOL/divertor model in WHIST to included radiation, and will extend it to treat ions and electrons separately in the near future; and we are upgrading the MHD capability in WHIST by incorporating VMEC. At the same time, our 0-D code is being upgraded to a multi-region model, by adding coupled edge and divertor models to the present core model, for a better study of the effects of edge conditions on the dynamics of a burning plasma. The 0-D model provides a capability to perform a large number of control studies, while the 1-1/2D model provides the capability to study the coupled dynamics of the plasma core and the SOL/divertor in detail.

B. PROPOSED WORK

It is proposed to continue our burn stability control studies during the EDA phase of the ITER project. Particular emphasis will be placed on issues that are identified by the JCT as critical. We anticipate that these will be similar to those which were identified as critical during the ITER CDA Burn Control Studies. Such issues may include the identification of credible burn control schemes and the assesssment of the associated technological requirements and of the effect of physics uncertainities, the definition of the minimum diagnostic requirements for controllability, the identification of worst case transients, the study of the effect of perturbations introduced by sawteeth oscillations and pellet injection on thermal stability, and the identification of phenomena and processes that can contribute to the inherent, passive stability of the system. Attention will also be given to thermal instabilities triggered by density fluctuations, a recent concern of the JCT. Such fluctuations (which earlier studies [9] have shown to give rise to distinct modes for certain confinement scalings) can be caused by desorption of fuel from the first wall of the device due to an increase in its temperature. The impurity influx that will most certainly accompany the fuel flux, should also be taken into account in the analysis of the response of the system.

We believe that our advanced computational capabilities make us qualified, perhaps uniquely so at this time, to study in detail any of these burn control problems. The impurity transport option that we added to the WHIST 1-1/2-D transport code will be especially useful for modelling scenarios involving wall-originated or externally introduced impurities and also for the simulation of off-normal operation, while our divertor and SOL model will give us an estimate of the effect that edge plasma conditions can have on the evolution of the core plasma during transients. Our computational tools will also allow us to examine edge phenomena control schemes that are based on physics that is currently less well understood (but with a rapidly expanding database) and which hold the promise of reducing the technological requirements and cost of the control system. Such schemes will be based on mechanisms that can be affected in the edge region and which interactively influence and control the core thermonuclear burn [10].

C. EFFORT, TIME & BUDGET

We envision that the US Burn Control effort in support of ITER would be of a multi-institutional nature, would be an ongoing activity and would be carried out at a level dictated by the urgency assigned to the task by the JCT. We believe that a fairly substantial effort early in the EDA would be wise.

We propose to involve a graduate student who is doing his Ph.D. research in this area 100%, Dr. Mandrekas 10% and Dr. Stacey 5% in the specific activities described above. The required support is about $50K/year, including fringe and overhead. (In addition to this proposed level of effort, we plan to propose continuation of our participation in the SUPERCODE activity, some part of which might naturally be part of the US Burn Control activity.) If necessary, this level of effort could be increased by the assignment of a Postdoctoral Research Scientist.

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Refer to: RDF/03.141.002.95.008
E-25-685

5 October 1994

U. S. Department of Energy
Oak Ridge Operations
Procurement and Contracts Division
Contract Management Branch
P.O. Box 2001
Oak Ridge, TN 37831-8758

Attention: Mr. Maurice Davis

Subject: Continuation Proposal for Grant No. DE-FG05-91ER54122

Dear Mr. Davis:

GEORGIA TECH RESEARCH CORPORATION is pleased to submit the enclosed proposal for your consideration. If you need any additional information, please contact us at your convenience. Technical matters should be referred to Dr. W. M. Stacey at 404/894-3714 and administrative matters to the undersigned at 404/894-4817. We look forward to hearing from you soon.

Sincerely,

R. Dennis Farmer
Contracting Officer

Addressee: Original + 7 copies
Enclosure: Proposal - Original + 7 copies

cc: Dr. Robert E. Price
U. S. Department of Energy
Office of Fusion Energy
ER-533
ITER & Technology Division
J-213/GTN
Washington, DC 20585 - One complete copy of proposal

Proposal To The
U. S. DEPARTMENT OF ENERGY
For Continuation of Research on
"SUPPORT OF U.S. ITER ACTIVITY"
DOE GRANT NO. DE-FG05-91ER54122

by

Fusion Research Center
Georgia Institute of Technology
Atlanta, Georgia 30332

September 23, 1994

Principal Investigator:	**Dr. W. M. Stacey**
Title:	**Callaway Professor**
Department Affiliation:	**Nuclear Engineering Program**
Telephone:	**(404) 894-3714**
Proposed Start Date:	**October 1, 1994**
Proposed Duration:	**1 Year**
Funding Requirements:	**$171,685**

Endorsements:

W. M. Stacey, Jr.	**W. M. Stacey, Jr., Director**
Principal Investigator	**Fusion Research Center**
Date: 9-23-94	**Date:** 9-23-94

DOE F 4650.2
(10/91)
(All Other Editions Are Obsolete)

OMB Control No.
1910-1400
(OMB Burden Disclosure)
Statement on Back)

Department of Energy
Office of Energy Research (OER)
Face Page

TITLE OF PROPOSED RESEARCH: Support of U.S. ITER Activity

PLEASE TYPE THE FOLLOWING INFORMATION:

1. CATALOG OF FEDERAL DOMESTIC ASSISTANCE NUMBER: 81.049

2. CONGRESSIONAL DISTRICT:
Applicant Organ's Dist.: Fifth
Project Site's Dist.:

3. I.R.S. ENTITY IDENTIFICATION OR SOCIAL SECURITY NUMBER:
58-0603146

4. AREA OF RESEARCH OR ANNOUNCEMENT TITLE/NUMBER
Nuclear Engineering

5. HAS THIS RESEARCH PROPOSAL BEEN SUBMITTED TO ANY OTHER FEDERAL AGENGY? [ ] yes [X] no
PLEASE LIST

6. DOE/OER PROGRAM STAFF CONTACT (IF KNOWN)
Robert E. Price, ER-533

7. TYPE OF APPLICATION: [ ] New [X] Continuation [ ] Supplement [ ] Renewal [ ] Revision

8. ORGANIZATION TYPE:
State Government [ ]
Indian Tribal Government [ ]
Inst. of Higher Educ [X]
(Small Business [ ]
Women-owned [ ]
Local Government [ ]
Non-Profit [X]
Individual [ ]
For-Profit [ ]
Disadvantage Bus. [ ]
Hospital [ ]
Other [ ]
8(a) [ ]

9. CURRENT DOE AWARD NUMBER (IF APPLICABLE)
DE-FG05-87ER52141

10. WILL THIS RESEARCH INVOLVE:
10A. Human Subjects [X] no [ ] If yes,
Exemption No. (or)
IRB Approval Date
Assurance of Compliance No.

10B. Vertebrate Animals [X] no [ ] If yes,
IACUC Approval Date
Animal Welfare Assur. No.

11. AMOUNT REQUESTED FROM DOE FOR ENTIRE PROJECT PERIOD $543,881

12. DURATION OF ENTIRE PROJECT PERIOD
6/1/91 to 9/30/95
Mo / day / yr. Mo / day / yr.

13. REQUESTED AWARD START DATE
10/1/94 (Mo / day / yr.)

14. IS APPLICANT DELINQUENT ON ANY FEDERAL DEBT?
[ ] Yes (If "Yes," attach an explanation)
[X] No

15. PRINCIPAL INVESTIGATOR/PROGRAM DIRECTOR NAME, TITLE, ADDRESS AND PHONE NUMBER

Dr. Weston M. Stacey
Regent's Professor
Fusion Research Center
Georgia Institute of Technology
Atlanta, GA 30332-0225

404/894-3714

W. M. Stacey

SIGNATURE OF PRINCIPAL INVESTIGATOR/
PROGRAM DIRECTOR

10/5/94
DATE

PI/PD ASSURANCE: I agree to accept responsibility for the scientific conduct of the project and to provide the required progress reports if an award is made as a result of this submission. Willful provision of false information is a criminal offense. (U.S.Code, Title 18, Section 1001).

16. ORGANIZATION'S NAME, ADDRESS AND CERTIFYING REPRESENTATIVE'S NAME, TITLE AND PHONE NUMBER
Georgia Tech Research Corporation
Centennial Research Building, Room 246
Georgia Institute of Technology
Atlanta, GA 30332-0420
R. Dennis Farmer / Contracting Officer
404/894-4817

SIGNATURE OF ORGANIZATION'S CERTIFYING REPRESENTATIVE

10/5/94
DATE

CERTIFICATION & ACCEPTANCE: I certify that the statements herein are true and complete to the best of my knowledge, and accept the obligation to comply with DOE terms and conditions if an award is made as the result of this submission. A willfully false certification is a criminal offense. (U.S. Code, Title 18, Section 1001).

Georgia Tech ITER Support
Grant # DE-FG05-9154122
Impurity Seeded Radiative Mantle

Summary

This is a three-year grant extending through 6/30/95. A 3-month extension of the grant, to get it on a fiscal year basis, and funding for 10/1/94-9/30/95 are proposed.

FY94 Results

Our calculations for ITER in FY94 and the experimental results from DIII-D have established the impurity-seeded radiative mantle concept as a leading candidate for solving the divertor heat load problem in ITER. The ITER Divertor Physics Expert Group identified the radiative mantle as the second item on their list of high-priority items. We have developed over the past two years what is, to my knowledge, the most comprehensive computational capability extant to analyze the radiating mantle. Our calculations in FY94 established that, for a representative ITER operating point and transport model and an Fe impurity, the impurity-seeded radiative mantle could reduce the heat flow into the SOL by 1-2 orders of magnitude, without adversely impacting the plasma power balance or altering the current profile in such a way as to produce disruptive collapse of the current channel.

FY95 Proposed Effort

The proposed effort is consistent with the scope of work of the grant.

We propose in FY95 to implement an improved SOL/Divertor transport model coupled to our state-of-the-art core transport capability and carry out analyses to investigate: 1) the robustness of the impurity-seeded radiative mantle for ITER with respect to different choices of impurity species, models for core transport, plasma operating conditions, and modes of divertor operation; and 2) the complementarity and compatibility of the impurity-seeded radiative mantle with the gaseous and radiative divertor in ITER. The proposed effort would require 17% of my time, 100% of the time of Dr. Mandrekas (who is the principal person for the computations) and 33% of the time of a PhD student (who is in the third year of his dissertation on this topic); with overhead, etc., this amounts to $171,685 for FY95.

Proposed Extension

A 3-month extension of the grant to 9/30/95 is proposed, to get it on a fiscal year basis.

DOE F 4620.1
(04-93)
All Other Editions Are Obsolete

U.S. Department of Energy
Budget Page
(See reverse for Instructions)

OMB Control No.
1910-1400
OMB Burden Disclosu
Statement on Reverse

ORGANIZATION
Georgia Tech Research Corporation

Budget Page No: ____________

PRINCIPAL INVESTIGATOR (PI)/PROJECT DIRECTOR (PD)
W. M. Stacey

Requested Duration: 12 (Months

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in bracket(s))	DOE Funded Person - mos CAL	ACAD	SUMR	Funds Requested by Applicant	Funds Grant by DOE
1. W. M. Stacey		1	1	21,000	
2. J. Mandrekas	12			59,000	
3.					
4.					
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)					
7. (2) TOTAL SENIOR PERSONNEL (1-6)				80,000	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. ( ) POST DOCTORAL ASSOCIATES					
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					
3. (1) GRADUATE STUDENTS				12,000	
4. ( ) UNDERGRADUATE STUDENTS					
5. (1) SECRETARIAL - CLERICAL				2,800	
6. ( ) OTHER					
TOTAL SALARIES AND WAGES (A + B)				94,800	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS) 24.7% of A6/B5; 1.5% - B3				20,632	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				115,432	
D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM)					
TOTAL PERMANENT EQUIPMENT					
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				6,000	
2. FOREIGN					
TOTAL TRAVEL				6,000	
F. TRAINEE/PARTICIPANT COSTS					
1. STIPENDS (itemize levels, types + totals on budget justification page)					
2. TUITION & FEES					
3. TRAINEE TRAVEL					
4. OTHER (fully explain on justification page)					
TOTAL PARTICIPANTS ( ) TOTAL COST					
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				700	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				500	
3. CONSULTANT SERVICES					
4. COMPUTER (ADP) SERVICES					
5. SUBCONTRACTS					
6. OTHER					
TOTAL OTHER DIRECT COSTS				1,200	
H. TOTAL DIRECT COSTS (A THROUGH G)				122,632	
I. INDIRECT COSTS (SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS 40.0% of MTDC				49,053	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				171,685	
K. AMOUNT OF ANY REQUIRED COST-SHARING FROM NON-FEDERAL SOURCES					
L. TOTAL COST OF PROJECT (J + K)				171,685	

DE-FG05-91ER54122

Materials and Supplies:

$500 - Publishing and distributing of report
200 - Duplication costs, library charges, mailing, etc.
$700

Publication:

$500 - 25 pages @ $20.00/page.

Travel:

$6,000 - To attend 2 required project meetings and 2 technical meetings. Locations are to be determined. See attachment.

TRAVEL COST ESTIMATE

estination: TBD
urpose: Technical Meeting
ersons/trip: 2
o. trips: 1
ights/trip: 5
ays/trip: 5

T Airfare:	$498	/person-trip	X	2 trips =	$996
otel:	$50	/person-night	X	10 nights=	500
ubsistence:	$35	/person-day	X	10 days =	350
ental Car:	$35	/day	X	5 days =	175
ocal travel:	$0.22	/mile	X	40 miles =	8.6
isc expenses:	$8	/person-day	X	10 days =	80

OTAL FOR TRIP #1 $2,110

estination: TBD
urpose: Technical Meeting
ersons/trip: 2
o. trips: 1
ights/trip: 5
ays/trip: 5

T Airfare:	$498	/person-trip	X	2 trips =	$996
otel:	$50	/person-night	X	10 nights=	500
ubsistence:	$35	/person-day	X	10 days =	350
ental Car:	$35	/day	X	5 days =	175
ocal travel:	$0.22	/mile	X	40 miles =	8.6
isc expenses:	$8	/person-day	X	10 days =	80

OTAL FOR TRIP #2 $2,110

estination: TBD
urpose: Project Meeting
ersons/trip: 1
o. trips: 1
ights/trip: 3
ays/trip: 3

T Airfare:	$498	/person-trip	X	1 trips =	$498
otel:	$50	/person-night	X	3 nights=	150
ubsistence:	$35	/person-day	X	3 days =	105
ental Car:	$35	/day	X	3 days =	105
ocal travel:	$0.22	/mile	X	40 miles =	8.6
isc expenses:	$8	/person-day	X	3 days =	24

OTAL FOR TRIP #3 $891

estination: TBD
urpose: Project Meeting
ersons/trip: 1
o. trips: 1
ights/trip: 3
ays/trip: 3

T Airfare:	$498	/person-trip	X	1 trips =	$498
otel:	$50	/person-night	X	3 nights=	150
ubsistence:	$35	/person-day	X	3 days =	105
ental Car:	$35	/day	X	3 days =	105
ocal travel:	$0.22	/mile	X	40 miles =	8.6
isc expenses:	$8	/person-day	X	3 days =	24

OTAL FOR TRIP #4 $891

ASSURANCES — NON-CONSTRUCTION PROGRAMS

ote: Certain of these assurances may not be applicable to your project or program. If you have questions, please contact the awarding agency. Further, certain Federal awarding agencies may require applicants to certify to additional assurances. If such is the case, you will be notified.

As the duly authorized representative of the applicant I certify that the applicant:

1. Has the legal authority to apply for Federal assistance, and the institutional, managerial and financial capability (including funds sufficient to pay the non-Federal share of project costs) to ensure proper planning, management and completion of the project described in this application.

2. Will give the awarding agency, the Comptroller General of the United States, and if appropriate, the State, through any authorized representative, access to and the right to examine all records, books, papers, or documents related to the award; and will establish a proper accounting system in accordance with generally accepted accounting standards or agency directives.

3. Will establish safeguards to prohibit employees from using their positions for a purpose that constitutes or presents the appearance of personal or organizational conflict of interest, or personal gain.

Will initiate and complete the work within the applicable time frame after receipt of approval of the awarding agency.

5. Will comply with the Intergovernmental Personnel Act of 1970 (42 U.S.C. §§ 4728-4763) relating to prescribed standards for merit systems for programs funded under one of the nineteen statutes or regulations specified in Appendix A of OPM's Standards for a Merit System of Personnel Administration (5 C.F.R. 900, Subpart F).

6. Will comply with all Federal statutes relating to nondiscrimination. These include but are not limited to: (a) Title VI of the Civil Rights Act of 1964 (P.L. 88-352) which prohibits discrimination on the basis of race, color or national origin; (b) Title IX of the Education Amendments of 1972, as amended (20 U.S.C. §§ 1681-1683, and 1685-1686), which prohibits discrimination on the basis of sex; (c) Section 504 of the Rehabilitation Act of 1973, as amended (29 U.S.C. § 794), which prohibits discrimination on the basis of handicaps; (d) the Age Discrimination Act of 1975, as amended (42 U.S.C.§§ 6101-6107), which prohibits discrimination on the basis of age; (e) the Drug Abuse Office and Treatment Act of 1972 (P.L. 92-255), as amended, relating to nondiscrimination on the basis of drug abuse; (f) the Comprehensive Alcohol Abuse and Alcoholism Prevention, Treatment and Rehabilitation Act of 1970 (P.L. 91-616), as amended, relating to nondiscrimination on the basis of alcohol abuse or alcoholism; (g) §§ 523 and 527 of the Public Health Service Act of 1912 (42 U.S.C. 290 dd-3 and 290 ee-3), as amended, relating to confidentiality of alcohol and drug abuse patient records; (h) Title VIII of the Civil Rights Act of 1968 (42 U.S.C § 3601 et seq.), as amended, relating to non-discrimination in the sale, rental or financing of housing; (i) any other nondiscrimination provisions in the specific statute(s) under which application for Federal assistance is being made; and (j) the requirements of any other nondiscrimination statute(s) which may apply to the application.

7. Will comply, or has already complied, with the requirements of Titles II and III of the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970 (P.L. 91-646) which provide for fair and equitable treatment of persons displaced or whose property is acquired as a result of Federal or federally assisted programs. These requirements apply to all interests in real property acquired for project purposes regardless of Federal participation in purchases.

8. Will comply with the provisions of the Hatch Act (5 U.S.C. §§ 1501-1508 and 7324-7328) which limit the political activities of employees whose principal employment activities are funded in whole or in part with Federal funds.

9. Will comply, as applicable, with the provisions of the Davis-Bacon Act (40 U.S.C. §§ 276a to 276a-7), the Copeland Act (40 U.S.C. § 276c and 18 U.S.C. §§ 874), and the Contract Work Hours and Safety Standards Act (40 U.S.C. §§ 327-333), regarding labor standards for federally assisted construction subagreements.

10. Will comply, if applicable, with flood insurance purchase requirements of Section 102(a) of the Flood Disaster Protection Act of 1973 (P.L. 93-234) which requires recipients in a special flood hazard area to participate in the program andto purchase flood insurance if the total cost of insurable construction and acquisition is $10,000 or more.

11. Will comply with environmental standards which may be prescribed pursuant to the following: (a) institution of environmental quality control measures under the National Environmental Policy Act of 1969 (P.L. 91-190) and Executive Order (EO) 11514; (b) notification of violating facilities pursuant to EO 11738; (c) protection of wetlands pursuant to EO 11990; (d) evaluation of flood hazards in floodplains in accordance with EO 11988; (e) assurance of project consistency with the approved State management program developed under the Coastal Zone Management Act of 1972 (16 U.S.C. §§ 1451 et seq.); (f) conformity of Federal actions to State (Clear Air) Implementation Plans under Section 176(c) of the Clear Air Act of 1955, as amended (42 U.S.C. § 7401 et seq.); (g) protection of underground sources of drinking water under the Safe Drinking Water Act of 1974, as amended, (P.L. 93-523); and (h) protection of endangered species under the Endangered Species Act of 1973, as amended, (P.L. 93-205).

12. Will comply with the Wild and Scenic Rivers Act of 1968 (16 U.S.C. §§ 1271 et seq.) related to protecting components or potential components of the national wild and scenic rivers system.

13. Will assist the awarding agency in assuring compliance with Section 106 of the National Historic Preservation Act of 1966, as amended (16 U.S.C. 470), EO 11593 (identification and protection of historic properties), and the Archaeological and Historic Preservation Act of 1974 (16 U.S.C. 469a-1 et seq.).

14. Will comply with P.L. 93-348 regarding the protection of human subjects involved in research, development, and related activities supported by this award of assistance.

15. Will comply with the Laboratory Animal Welfare Act of 1966 (P.L. 89-544, as amended, 7 U.S.C. 2131 et seq.) pertaining to the care, handling, and treatment of warm blooded animals held for research, teaching, or other activities supported by this award of assistance.

16. Will comply with the Lead-Based Paint Poisoning Prevention Act (42 U.S.C. §§ 4801 et seq.) which prohibits the use of lead based paint in construction or rehabilitation of residence structures.

17. Will cause to be performed the required financial and compliance audits in accordance with the Single Audit Act of 1984.

18. Will comply with all applicable requirements of all other Federal laws, executive orders, regulations and policies governing this program.

SIGNATURE OF AUTHORIZED CERTIFYING OFFICIAL	TITLE
R. Dennis Farmer	Contracting Officer
APPLICANT ORGANIZATION	**DATE SUBMITTED**
Georgia Tech Research Corporation	10/5/94

DOE F 1600.5
(10-86)

OMB Contol No.
1910-0400

U.S. Department of Energy

Assurance of Compliance

Nondiscrimination in Federally Assisted Programs

Georgia Tech Research Corporation (Hereinafter called the "Applicant") HEREBY AGREES to comply with Title VI of the Civil Rights Act of 1964 (Pub. L. 88-352), Section 16 of the Federal Energy Administration Act of 1974 (Pub. L. 93-275), Section 401 of the Energy Reorganization Act of 1974 (Pub. L. 93-438), Title IX of the Education Amendments of 1972, as amended, (Pub. L. 92-318, Pub. L. 93-568, and Pub. L. 94-482), Section 504 of the Rehabilitation Act of 1973 (Pub. L. 93-112), the Age Discrimination Act of 1975 (Pub. L. 94-135), Title VIII of the Civil Rights Act of 1968 (Pub. L. 90-284), the Department of Energy Organization Act of 1977 (Pub. L. 95-91), and the Energy Conservation and Production Act of 1976, as amended, (Pub. L. 94-385). In accordance with the above laws and regulations issued pursuant thereto, the Applicant agrees to assure that no person in the United States shall, on the ground of race, color, national origin, sex, age, or handicap, be excluded from participation in, be denied the benefits of, or be otherwise subjected to discrimination under any program or activity in which the Applicant receives Federal assistance from the Department of Energy.

Applicability and Period of Obligation

In the case of any service, financial aid, covered employment, equipment, property, or structure provided, leased, or improved with Federal assistance extended to the Applicant by the Department of Energy, this assurance obligates the Applicant for the period during which Federal assistance is extended. In the case of any transfer of such service, financial aid, equipment, property, or structure, this assurance obligates the transferee for the period during which Federal assistance is extended. If any personal property is so provided, this assurance obligates the Applicant for the period during which it retains ownership or possession of the property. In all other cases, this assurance obligates the Applicant for the period during which the Federal assistance is extended to the Applicant by the Department of Energy.

Employment Practices

Where a primary objective of the Federal assistance is to provide employment or where the Applicant's employment practices affect the delivery of services in programs or activities resulting from Federal assistance extended by the Department, the Applicant agrees not to discriminate on the ground of race, color, national origin, sex, age, or handicap, in its employment practices. Such employment practices may include, but are not limited to, recruitment, recruitment advertising, hiring, layoff or termination, promotion, demotion, transfer, rates of pay, training and participation in upward mobility programs; or other forms of compensation and use of facilities.

Subrecipient Assurance

The Applicant shall require any individual, organization, or other entity with whom it subcontracts, subgrants, or subleases for the purpose of providing any service, financial aid, equipment, property, or structure to comply with laws cited above. To this end, the subrecipient shall be required to sign a written assurance form, however, the obligation of both recipient and subrecipient to ensure compliance is not relieved by the collection or submission of written assurance forms.

Data Collection and Access to Records

The Applicant agrees to compile and maintain information pertaining to programs or activities developed as a result of the Applicant's receipt of Federal assistance from the Department of Energy. Such information shall include, but is not limited to,the following: (1) the manner in which services are or will be provided and related data necessary for determining whether any persons are or will be denied such services on the basis of prohibited discrimination; (2) the population eligible to be served by race, color, national origin, sex, age and handicap; (3) data regarding covered employment including use or planned use of bilingual public contact employees serving beneficiaries of the program where necessary to permit effective participation by beneficiaries unable to speak or understand English; (4) the location of existing or proposed facilities connected with the program and related information adequate for determining whether the location has or will have the effect of unnecesarily denying access to any person on the basis of prohibited discrimination; (5) the present or proposed membership by race, color, national origin, sex, age and handicap, in any planning or advisory body which is an integral part of the program; and (6) any additional written data determined by the Department of Energy to be relevant to its obligation to assure compliance by recipients with laws cited in the first paragraph of this assurance.

The Applicant agrees to submit requested data to the Department of Energy regarding programs and activities developed by the Applicant from the use of Federal assistance funds extended by the Department of Energy. Facilities of the Applicant (including the physical plants, buildings, or other structures) and all records, books, accounts, and other sources of information pertinent to the Applicant's compliance with the civil rights laws shall be made available for inspection during normal business hours on request of an officer or employee of the Department of Energy specifically authorized to make such inspections. Instructions in this regard will be provided by the Director, Office of Equal Opportunity, U.S. Department of Energy.

This assurance is given in consideration of and for the purpose of obtaining any and all Federal grants, loans, contracts (excluding procurement contracts), property, discounts or other Federal assistance extended after the date hereto, to the Applicants by the Department of Energy, including installment payments on account after such data of application for Federal assistance which are approved before such date. The Applicant recognizes and agrees that such Federal assistance will be extended in reliance upon the representations and agreements made in this assurance and the the United States shall have the right to seek judicial enforcement of this assurance. This assurance in binding on the Applicant, its successors, transferees, and assignees, as well as the person whose signature appears below and who is authorized to sign this assurance on behalf of the Applicant.

10/5/94
(Date)

Georgia Tech Research Corporation

Centennial Research Building
(Name of Applicant)

Georgia Institute of Technology

Atlanta, GA 30332-0420
(Address)

[signature]
(Authorized Official) R. Dennis Farmer, Contracting Officer

( ) 404/894-4817
(Applicant's Telephone Number)

CERTIFICATIONS REGARDING LOBBYING; DEBARMENT, SUSPENSION AND OTHER RESPONSIBILITY MATTERS; AND DRUG-FREE WORKPLACE REQUIREMENTS

Applicants should refer to the regulations cited below to determine the certification to which they are required to attest. Applicants should also review the instructions for certification included in the regulations before completing this form. Signature of this form provides for compliance with certification requirements under 34 CFR Part 82, "New Restrictions on Lobbying," and 34 CFR Part 85, "Government-wide Debarment and Suspension (Nonprocurement) and Government-wide Requirements for Drug-Free Workplace (Grants)." The certifications shall be treated as a material representation of fact upon which reliance will be placed when the Department of Energy determines to award the covered transaction, grant, or cooperative agreement.

1. LOBBYING

The undersigned certifies, to the best of his or her knowledge and belief, that:

(1) No Federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any Federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.

(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, "Disclosure Form to Report Lobbying," in accordance with its instructions.

(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers (including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements) and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

2. DEBARMENT, SUSPENSION, AND OTHER RESPONSIBILITY MATTERS

(1) The prospective primary participant certifies to the best of its knowledge and belief, that it and its principals:

(a) Are not presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency;

(b) Have not within a three-year period preceding this proposal been convicted of or had a civil judgment rendered against them for commission of fraud or a criminal offense in connection with obtaining, attempting to obtain, or performing a public (Federal, State or local) transaction or contract under a public transaction; violation of Federal or State antitrust statutes or commission of embezzlement, theft, forgery, bribery, falsification or destruction of records, making false statements, or receiving stolen property;

(c) Are not presently indicted for or otherwise criminally or civilly charged by a governmental entity (Federal, State or local) with commission of any of the offenses enumerated in paragraph (1)(b) of this certification; and

(d) Have not within a three-year period preceding this application/proposal had one or more public transactions (Federal, State or local) terminated for cause or default.

(2) Where the prospective primary participant is unable to certify to any of the statements in this certification, such prospective participant shall attach an explanation to this proposal.

3. DRUG-FREE WORKPLACE

This certification is required by the Drug-Free Workplace Act of 1988 (Pub. L. 100-690, Title V, Subtitle D) and is implemented through additions to the Debarment and Suspension regulations, published in the Federal Register on January 31, 1989, and May 25, 1990.

ALTERNATE I
(GRANTEES OTHER THAN INDIVIDUALS)

(1) The grantee certifies that it will or will continue to provide a drug-free workplace by:

(a) Publishing a statement notifying employees that the unlawful manufacture, distribution, dispensing, possession, or use of a controlled substance is prohibited in the grantee's workplace and specifying the actions that will be taken against employees for violation of such prohibition;

(b) Establishing an ongoing drug-free awareness program to inform employees about:

(1) The dangers of drug abuse in the workplace;

(2) The grantee's policy of maintaining a drug-free workplace;

(3) Any available drug counseling, rehabilitation, and employee assistance programs; and

(4) The penalties that may be imposed upon employees for drug abuse violations occurring in the workplace;

(c) Making it a requirement that each employee to be engaged in the performance of the grant be given a copy of the statement required by paragraph (a);

(d) Notifying the employee in the statement required by paragraph (a) that, as a condition of employment under the grant, the employee will:

(1) Abide by the terms of the statement; and

(2) Notify the employer in writing of his or her conviction for a violation of a criminal drug statute occurring in the workplace not later than five calendar days after such conviction;

(e) Notifying the agency, in writing, within ten calendar days after receiving notice under subparagraph (d)(2) from an employee or otherwise receiving actual notice of such conviction. Employers of convicted employees must provide notice, including position title, to every grant officer or other designee on whose grant activity the convicted employee was working, unless the Federal agency has designated a central point for the receipt of such notices. Notice shall include the identification number(s) of each affected grant;

(f) Taking one of the following actions, within 30 calendar days of receiving notice under subparagraph (d)(2), with respect to any employee who is so convicted:

(1) Taking appropriate personnel action against such an employee, up to and including termination, consistent with the requirements of the Rehabilitation Act of 1973, as amended; or

(2) Requiring such employee to participate satisfactorily in a drug abuse assistance or rehabilitation program approved for such purposes by a Federal, State, or local health, law enforcement, or other appropriate agency;

(g) Making a good faith effort to continue to maintain a drug-free workplace through implementation of paragraphs (a), (b), (c), (d), (e), and (f).

(2) The grantee may insert in the space provided below the site(s) for the performance of work done in connection with the specific grant:

Place of Performance:
(Street address, city, county, state, zip code)

225 North Avenue

Atlanta, Fulton County, Georgia 30332

☐ Check if there are workplaces on file that are not identified here.

ALTERNATE II (GRANTEES WHO ARE INDIVIDUALS)

(1) The grantee certifies that, as a condition of the grant, he or she will not engage in the unlawful manufacture, distribution, dispensing, possession, or use of a controlled substance in conducting any activity with the grant.

(2) If convicted of a criminal drug offense resulting from a violation occurring during the conduct of any grant activity, he or she will report the conviction, in writing, within 10 calendar days of the conviction, to every grant officer or other designee, unless the Federal agency designates a central point for the receipt of such notices. When notice is made to such a central point, it shall include the identification number(s) of each affected grant.

As the duly authorized representative of the applicant, I hereby certify that the applicant will comply with the above certifications.

NAME OF APPLICANT	PR/AWARD NUMBER AND/OR PROJECT NAME
Georgia Tech Research Corporation	
PRINTED NAME AND TITLE OF AUTHORIZED REPRESENTATIVE R. Dennis Farmer Contracting Officer	
SIGNATURE	DATE 10/5/94